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BULLETIN
of the
American Association *of* Petroleum Geologists

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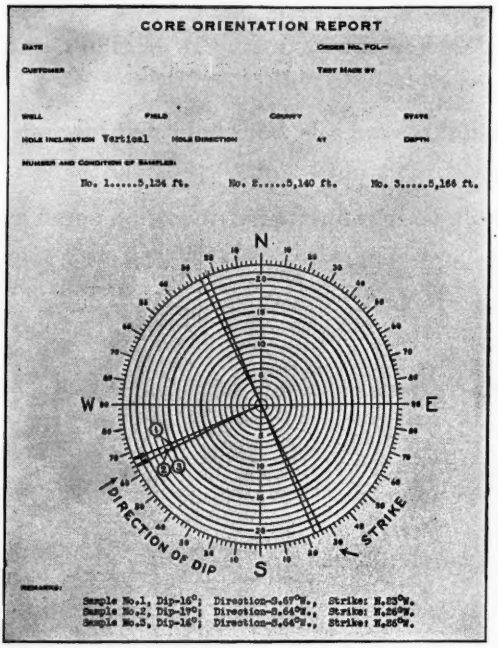

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Volume 25 Number 4

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

APRIL, 1941

CORRELATION OF CRUDE OILS WITH SPECIAL REFERENCE TO CRUDE OIL OF GULF COAST[1]

DONALD C. BARTON[2]

ABSTRACT

The pattern of the graph of the derivation-from-the-mean of the difference between the A.P.I. gravity of adjacent cuts in the United States Bureau of Mines Hempel analyses of crude oil is reasonably characteristic of the crude oil of individual reservoirs and is reasonably invariant in the face of drastic artificial oxidation and weathering. Wide variation is shown by the various crude oils of Texas, Louisiana, Arkansas, and Oklahoma. In many cases, the patterns for the crude oils or part of the crude oils from approximately the same or approximately equivalent formations will show mutual similarity which is very much closer than their resemblance to the patterns of other crude oils. Drastic difference is present in a few cases between patterns of crude oils from the same sand (examples: Woodbine, "Wilcox sand" of Oklahoma). The presumption seems justified that in general but not universally very close similarity in pattern indicates genetic relationship for the corresponding crude oils. The presumption is yet stronger that drastic difference in pattern necessarily indicates difference in origin or history for the crude oils in question. These patterns offer a usably good but not perfect means of studying the genetic relationships and non-relationships of crude oils.

These conclusions are based on a rapid reconnaissance of the patterns for the Pennsylvanian and Permian crude oils of Texas, of the Oklahoma crude oils, and of the Cretaceous crude oils of Texas, Louisiana, and Arkansas, a few special detailed studies, and a detailed study of the patterns of Gulf Coast crudes.

The following theoretical conclusions seem to follow from the similarities and non-similarities of pattern and from the stratigraphic and areal occurrence of the Gulf Coast crude oils. The most common Plio-Miocene and younger Miocene crude oils can not be migrant older oils. The older Miocene (post-*Discorbis* zone) crude oils and a group of "Oligocene" (post-Vicksburg) crude oils can not be migrant oils of the most common Eocene and "Oligocene" types. Most of the source beds are decidedly limited in occurrence; and part of the variation in prolificness of adjacent structures is the effect of lensing in and out of the source beds. In spite of evidence against vertical migration at either place, some common factor producing similarity of pattern has affected crude oils through most of the Miocene section at Lockport, Louisiana; and a similar factor has affected crude oils through all but the uppermost part of the Miocene section at Spindletop, Texas. Part of the similarity in pattern between crude oils of adjacent ages is the effect of persistence of similarity of source conditions over a period of time. This pattern holds reasonably invariant in face of variation of the base from naphthenic to paraffinic. This more detailed study of the Gulf Coast crude oils through their A.P.I. gravity patterns really is only an extremely rapid reconnaissance into a new field and it indicates great promise for further research.

[1] Edited manuscript received, November 15, 1940.

[2] Deceased, July 8, 1939.

EDITOR'S NOTE

This paper represents a compilation with minor revision of the notes used by the author in his presidential address before the annual meeting of the Association at Oklahoma City, Oklahoma, March 22, 1939; and of the manuscript of a preliminary draft of a comprehensive paper planned for later publication by the author on the same subject. Margaret Fowles Barton, the author's widow, and Virgil Moore, his assistant, assembled the notes, manuscript and illustrations. Virgil Moore compiled a first draft of the present manuscript and drew the accompanying graphs. W. P. Haynes rearranged and edited this manuscript which took final form after consultation with and further slight editing by the undersigned.

It has seemed best, in the interest of clarity, not to leave the author's notes in the fragmentary form which served him in the delivery of his address. At the same time, it was clearly desirable to preserve as far as possible his diction and arrangement. Above all the attempt has been made to record the results of the author's studies of the "gravity-interval pattern" which he devised and endeavored to employ as a standard for the identification of crude oils. His graphs of the gravity-interval patterns of Gulf Coast oils and his correlation of these oils by their gravity-interval patterns deserve further study by his fellow research workers.

WALLACE E. PRATT

INTRODUCTION

Discussion of the source and migration of crude oils is invariably beclouded by the lack of any reliable criterion which will serve to distinguish one crude from another, or will permit the identification of a given crude oil throughout all stages of its life history. Many of us believe that crude oils migrate upward across the bedding planes from great depths, but our belief rests on indirect evidence. Seldom, if ever, can we identify a given shallow occurrence certainly with the deep-lying counterpart or parent-accumulation from which we believe it to be derived. The presence in a single blanket sand or geologic horizon spread uniformly over a greater area, of a series of pools or concentrations of crude oils generally similar in character, is widely interpreted as evidence for the common origin of the entire series of crude oils, either in the reservoir sand itself or in the immediately adjacent beds, above or below the sand. But in this case again we have no secure index for determining the degree of kinship between the several crude oils. We can not identify a given crude oil with its parent or distinguish crude oils of diverse parenthood. The solution of these problems would be expedited if we could establish the existence of and learn to recognize some type of invariant property in crude oils that remains constant and unchanging throughout the course of their normal evolution.

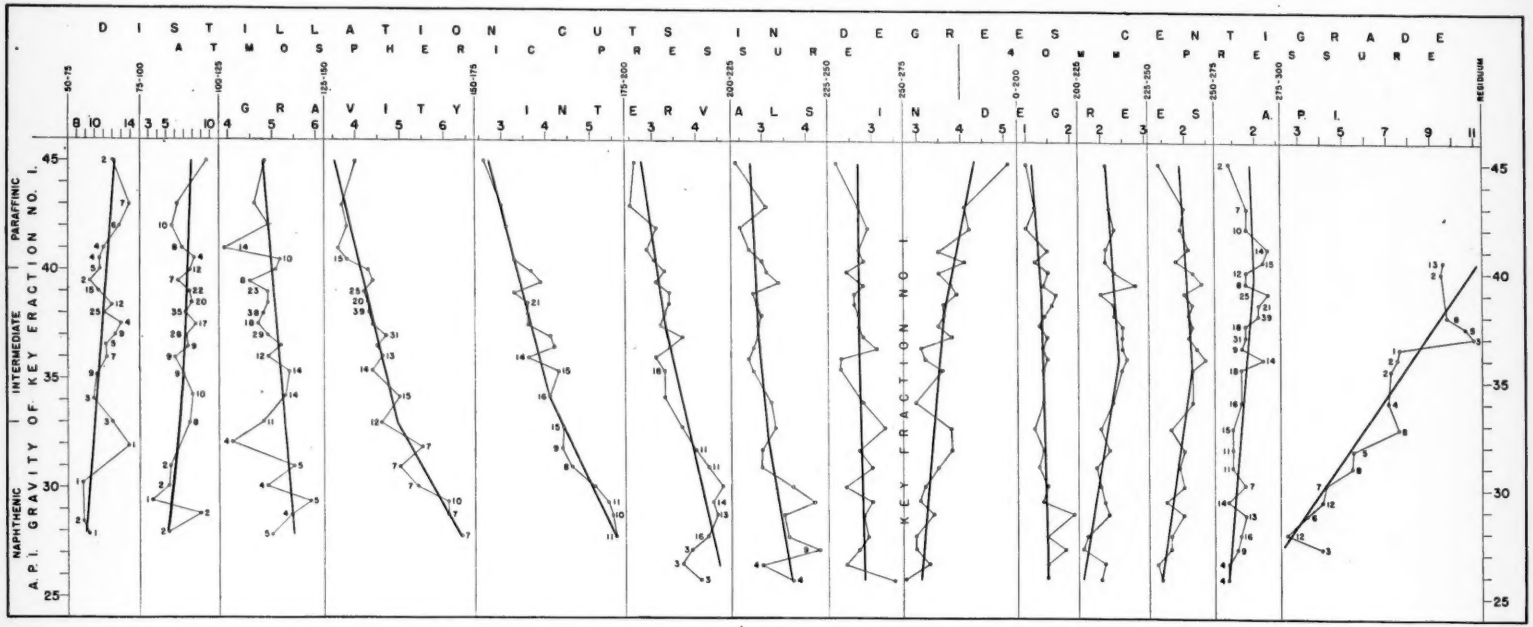
DISTILLATION CUTS IN DEGREES CENTIGRADE
ATMOSPHERIC PRESSURE
40 MM PRESSURE
50-75
75-100
100-125
125-150
150-175
175-200
200-225
225-250
250-275
0-200
200-225
225-250
250-275
275-300
REDIUM
GRAVITY
INTERVALS
IN DEGREES
A.P.I.
NAPHTHENIC
INTERMEDIATE
PARAFFINIC
A.P.I. GRAVITY OF KEY FRACTION NO. I.
KEY FRACTION NO. I
45
40
35
30
25

FIG. 1

TABLE I

NORMAL A.P.I. GRAVITY INTERVALS

Fractions, °C.	50–75	75–100	100–125	125–150	150–175	175–200	200–225	225–250	250–275	0–200	200–225	225–250	250–275	275–300	Residue
Key Fr. No. 1		Atmospheric Pressure Gravity Interval in Degrees A.P.I.								40 Millimeters Pressure Gravity Interval in Degrees A.P.I.					
		C	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*P*
45° A.P.I.		12.3	—	4.8	3.6	2.8	2.8	2.7	2.7	4.2	1.1	2.1	2.0	1.9	—
44		12.0	—	4.8	3.7	2.9	2.9	2.8	2.7	4.2	1.1	2.1	2.0	1.9	—
43		11.8	7.8	4.8	3.8	3.0	3.0	2.8	2.7	4.1	1.2	2.2	2.0	2.0	—
42		11.7	7.7	4.8	3.9	3.1	3.0	2.8	2.7	4.0	1.3	2.2	2.0	2.0	—
41		11.6	7.7	4.8	4.0	3.2	3.1	2.9	2.7	3.9	1.3	2.3	2.0	2.0	—
40		11.4	7.6	4.8	4.1	3.4	3.2	2.9	2.7	3.8	1.4	2.3	2.0	2.0	10.6
Paraffine base															
Intermediate base															
39		11.3	7.5	4.9	4.2	3.5	3.2	2.9	2.7	3.7	1.4	2.3	2.1	2.0	10.0
38		11.1	7.4	4.9	4.3	3.7	3.3	2.9	2.7	3.6	1.4	2.4	2.1	2.0	9.3
37		10.9	7.3	4.9	4.5	3.8	3.4	3.0	2.7	3.6	1.4	2.4	2.1	1.9	8.7
36		10.7	7.2	5.0	4.6	3.9	3.5	3.0	2.7	3.5	1.4	2.4	2.1	1.9	8.1
35		10.5	7.1	5.0	4.7	4.1	3.6	3.0	2.7	3.5	1.4	2.4	2.2	1.8	7.4
34		10.3	6.8	5.1	4.8	4.3	3.7	3.1	2.8	3.5	1.4	2.3	2.1	1.8	6.8
Intermediate base															
Naphthene base															
33		10.1	6.5	5.1	4.9	4.5	3.8	3.1	2.8	3.4	1.4	2.2	2.1	1.8	6.1
32		9.9	6.3	5.2	5.1	4.7	3.9	3.2	2.8	3.4	1.4	2.2	2.0	1.7	5.5
31		9.7	6.0	5.2	5.4	4.9	4.0	3.3	2.8	3.3	1.4	2.2	1.9	1.7	4.8
30		9.4	5.7	5.3	5.7	5.1	4.2	3.4	2.8	3.3	1.4	2.0	1.8	1.7	4.2
29		9.2	5.4	5.4	6.0	5.3	4.3	3.5	2.8	3.2	1.5	1.9	1.8	1.6	3.5
28		9.0	5.2	5.5	6.3	5.6	4.4	3.5	2.8	3.2	1.5	1.8	1.7	1.6	2.9
27		—	—	—	—	—	4.5	3.6	2.8	3.2	1.5	1.7	1.6	1.6	—
26		—	—	—	—	—	4.6	3.7	2.8	3.1	1.5	1.7	1.5	1.5	—

These intervals are taken from the smoothed curves of the graphs of Figure 1.

DEFINITION OF GRAVITY-INTERVAL PATTERN

The writer is proposing a "gravity-interval pattern" to serve as such an invariant characteristic for the identification of crude oils. This gravity-interval pattern is based on analyses made by the United States Bureau of Mines by the Hempel method. In this method a distillation cut is taken at 50°C. and at every 25°C. thereafter up to 275°C. under atmospheric pressure; and at 200°C. and every 25° thereafter up to 300°C. at a pressure of 40 mm. of mercury. The A.P.I. gravity of each of these cuts is determined and this record serves for the portrayal of the gravity-interval pattern of each crude oil. All available United States Bureau of Mines analyses were used in this compilation. These were first classified according to type of base, that is, paraffine or naphthene. For this purpose the A.P.I. gravity of key fraction No. 1, which is the last fraction obtained when distilling at atmospheric pressure by the Hempel method, is taken as an index. All crude oils in which key fraction No. 1 has an A.P.I. gravity of 40° or lighter are called paraffinic; those between 33° and 40° are classed as intermediate and those of 33° gravity or heavier are called naphthenic.[3]

All analyses of crude oils with the same gravity for key fraction No. 1, measured in degrees, A.P.I., are then taken and the interval in degrees A.P.I. between each cut is noted. These intervals are averaged and plotted in graph form (Fig. 1) using the gravities of key fractions No. 1 as ordinates and the gravity intervals as abscissae. The irregular graph for each interval is afterward represented by a smoothed curve and the mean values of the intervals in A.P.I. degrees are listed in tabular form (Table I) for ready reference in compiling graphs of gravity-interval patterns for various crude oils.

All of the graphs used as illustrations for the gravity-interval pattern in this study are constructed as follows. 1. The respective intervals are calculated for a given analysis. 2. The gravity of the key fraction No. 1 is noted on Table I and the respective normal gravity intervals between each cut of the type crude of this key fraction No. 1 are subtracted from the intervals of the given analysis. The resulting differences in A.P.I. degrees are plotted as ordinates and the successive distillation-cut intervals as abscissae. For convenience the latter are indicated respectively by letters *B* to *P*. The graph is considered, in a way, as the signature of the crude oil in question and the graphs of various crude oils serve as a means for their comparison with each other.

[3] See *U. S. Bur. Mines Bull. 401*, pp. 148 and 149.

NATURE OF CRUDE OIL

In suggesting that the gravity-interval pattern may furnish an invariant characteristic for comparison the writer has reasoned along the following lines. Crude oils are complex mixtures of members of the very complex family of petroleum hydrocarbons (together with compounds of nitrogen, sulphur, oxygen, *et cetera*). We do not exactly know what the source material of crude oil is but we may surmise that in general the source material is an aggregate of different forms of life and that by the laws of chance in an evolving, ever-changing world, aggregates formed at different geologic times will not be identical, and that slight differences in source materials will produce corresponding slight differences in the original character of crude oils. Slight differences in character between the original crude oils, in turn, will mean slight differences in the character of the individual cuts, and therefore slight differences in the gravity of those cuts. By the laws of chance the magnitude of the differences for the several fractions will vary with different crude oils. The pattern of the differences between the gravities of adjacent cuts, therefore, will show an individuality for each group of genetically related crude oils. This leads us further to the expectation that possibly evolutionary changes in the character of the crude oil will not selectively influence one cut more than another, but will influence all cuts more or less alike. Such changes might be expected to affect the general level of the gravities of the individual cuts without modifying profoundly the general pattern. We should, however, be on the watch for selective effects.

The idea that oils from contemporaneous source beds are similar rests on three postulates: first, the source material, or the aggregation of source materials, collecting contemporaneously under like conditions throughout the same general area is uniform in composition and produces crude oils originally identical in character; second, the source material or aggregation of source materials, collecting during different geologic periods in the same area, varies on account of changes in the types of life or changes in relative concentrations of the different types of life forming the source material, and therefore produces crude oils differing at least slightly in original character; third, one type of individual differences in character is fairly insensitive to forces causing considerable change in most of the other characters of the crude oils. Our first object is to show qualitative justification for these assumptions and for the use of the gravity-interval pattern as such an invariant characteristic, and to give a broader background for the more detailed use of the gravity-interval pattern in the study of the Gulf Coast crude oils.

The properties commonly used to describe crude oils are of little or no use in attempts to classify crude oils genetically. The specific gravity, or A.P.I. or Beaumé gravity, commonly varies considerably at different levels in the oil in a single reservoir; yet it may be identical for oils of rather different character. It also seems to undergo change with depth. The composition of a crude oil in terms of the percentage content of gasoline, kerosene, lubricating fractions, and residuum, or in terms of the base of the crude, are slightly better criteria, but the results of studies which the writer has already reported indicate that all these properties undergo changes which are proportional to time and to the depth of burial.[4]

A most interesting application of a wholly different type of criterion from that which the writer proposes has recently been made by J. McConnell Sanders.[5] He has found seemingly indigenous fragments of insects, spores, *et cetera*, part of them identifiable, in crude oils, and he correlates like crude oils by like contents of such fossils.

RELIABILITY OF GRAVITY-INTERVAL PATTERN

The writer's studies have shown that the gravity-interval pattern is reasonably characteristic of the oil within a single reservoir and that graphs from various samples although not identical show a family resemblance. Individual differences are usually less than 0.4°; and such a difference may be due to analytical inaccuracy or variation in the character of the same crude oil. Graphs drawn for samples from the three fields, East Texas, Panhandle, and Chapman, show that the pattern is usably constant but that single samples from different reservoirs hardly suffice for making conclusions in regard to the relationships of the oils. The pattern used as characteristic of a particular crude should be the mean pattern of three or more different samples from different parts of the reservoir.

Samples of oil subjected to drastic experimental oxidation by the United States Bureau of Mines showed that the effects of oxidation were slight and did not appreciably change the patterns although the gravity was slightly lowered. A sample of weathered crude oil was compared with a fresh sample and showed a loss of 8 per cent including

[4] 1. D. C. Barton, "Natural History of Gulf Coast Crude Oil," in *Problems of Petroleum Geology* (Amer. Assoc. Petrol. Geol., 1934), pp. 109–155.
2. *Idem*, "Variation and Migration of Crude Oil at Spindletop, Jefferson County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 618–43.
3. *Idem*, "Evolution of Gulf Coast Crude Oil," *ibid.*, Vol. 21, No. 7 (July, 1937), pp. 914–46.

[5] J. McConnell Sanders, "Microscopic Examination of Crude Petroleum," *Bull. Inst. Petrol. Tech.*, Vol. 23, No. 167, pp. 525–73.

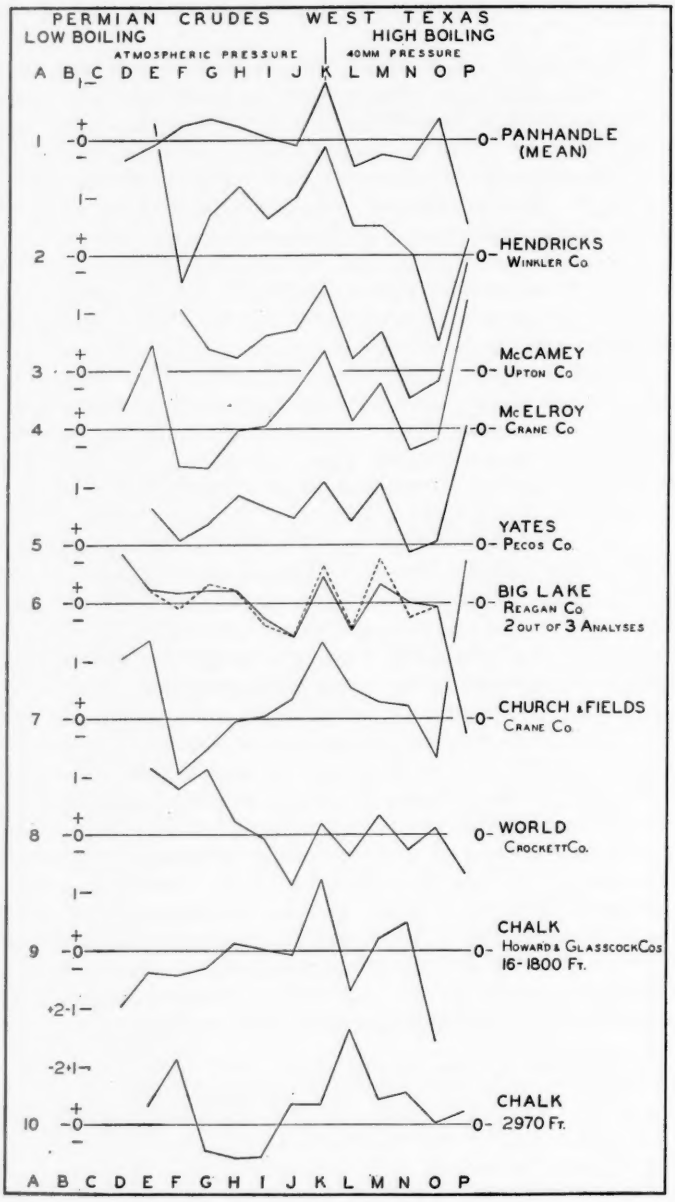
PERMIAN CRUDES WEST TEXAS
LOW BOILING
HIGH BOILING
ATMOSPHERIC PRESSURE
40MM PRESSURE
A B C D E F G H I J K L M N O P
1
PANHANDLE (MEAN)
HENDRICKS Winkler Co
McCAMEY Upton Co
McELROY Crane Co
YATES Pecos Co
BIG LAKE Reagan Co 2 out of 3 Analyses
CHURCH & FIELDS Crane Co
WORLD Crockett Co.
CHALK Howard & Glasscock Cos 16-1800 Ft.
CHALK 2970 Ft.
A B C D E F G H I J K L M N O P

FIG. 2

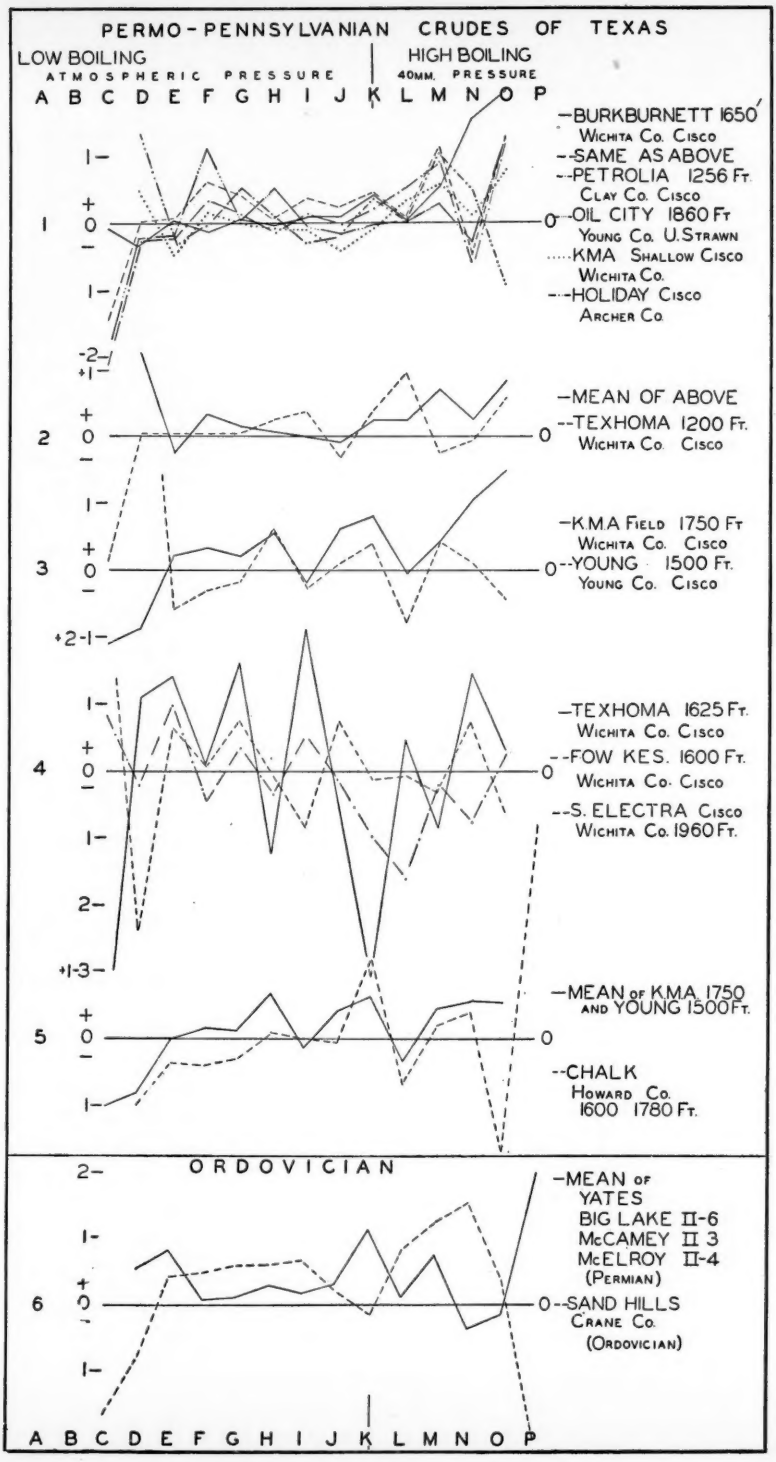
PERMO-PENNSYLVANIAN CRUDES OF TEXAS
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM. PRESSURE
A B C D E F G H I J K L M N O P
—BURKBURNETT 1650'
Wichita Co. Cisco
--SAME AS ABOVE
--PETROLIA 1256 Ft.
Clay Co. Cisco
--OIL CITY 1860 Ft
Young Co. U. Strawn
.....KMA Shallow Cisco
Wichita Co.
---HOLIDAY Cisco
Archer Co.
1
—MEAN OF ABOVE
--TEXHOMA 1200 Ft.
Wichita Co. Cisco
2
—K.M.A Field 1750 Ft
Wichita Co. Cisco
--YOUNG 1500 Ft.
Young Co. Cisco
3
—TEXHOMA 1625 Ft.
Wichita Co. Cisco
--FOW KES. 1600 Ft.
Wichita Co. Cisco
--S. ELECTRA Cisco
Wichita Co. 1960 Ft.
4
—MEAN of K.M.A. 1750
and YOUNG 1500 Ft.
--CHALK
Howard Co.
1600 1780 Ft.
5
ORDOVICIAN
—MEAN of
YATES
BIG LAKE II-6
McCAMEY II 3
McELROY II-4
(Permian)
--SAND HILLS
Crane Co.
(Ordovician)
6
A B C D E F G H I J K L M N O P

FIG. 3

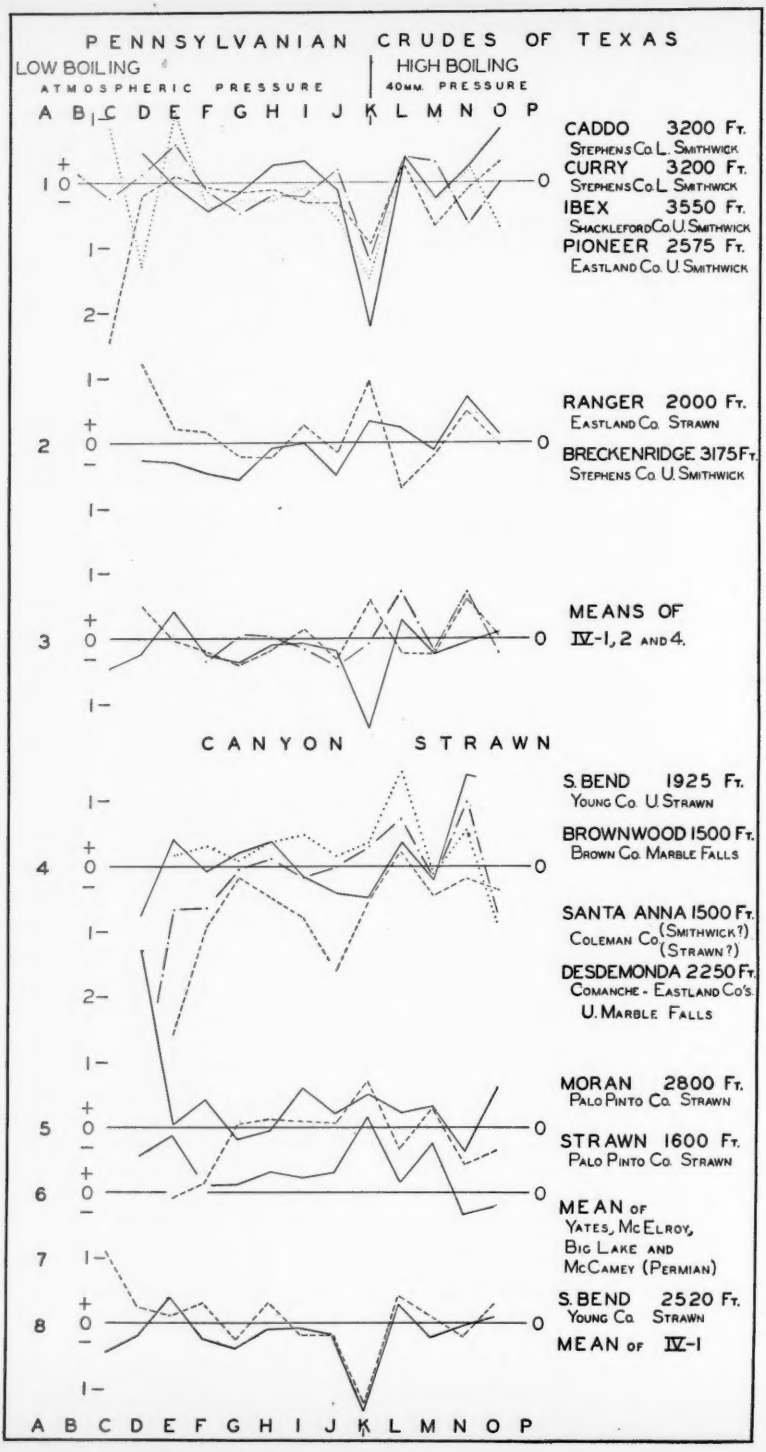
PENNSYLVANIAN CRUDES OF TEXAS
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM. PRESSURE
A B C D E F G H I J K L M N O P
CADDO 3200 FT.
STEPHENS CO. L. SMITHWICK
CURRY 3200 FT.
STEPHENS CO. L. SMITHWICK
IBEX 3550 FT.
SHACKLEFORD CO. U. SMITHWICK
PIONEER 2575 FT.
EASTLAND CO. U. SMITHWICK
RANGER 2000 FT.
EASTLAND CO. STRAWN
BRECKENRIDGE 3175 FT.
STEPHENS CO. U. SMITHWICK
MEANS OF
IV-1, 2 AND 4.
CANYON
STRAWN
S. BEND 1925 FT.
YOUNG CO. U. STRAWN
BROWNWOOD 1500 FT.
BROWN CO. MARBLE FALLS
SANTA ANNA 1500 FT.
COLEMAN CO. (SMITHWICK?)
(STRAWN?)
DESDEMONDA 2250 FT.
COMANCHE - EASTLAND CO'S.
U. MARBLE FALLS
MORAN 2800 FT.
PALO PINTO CO. STRAWN
STRAWN 1600 FT.
PALO PINTO CO. STRAWN
MEAN OF
YATES, MCELROY,
BIG LAKE AND
MCCAMEY (PERMIAN)
S. BEND 2520 FT.
YOUNG CO. STRAWN
MEAN OF IV-1

FIG. 4

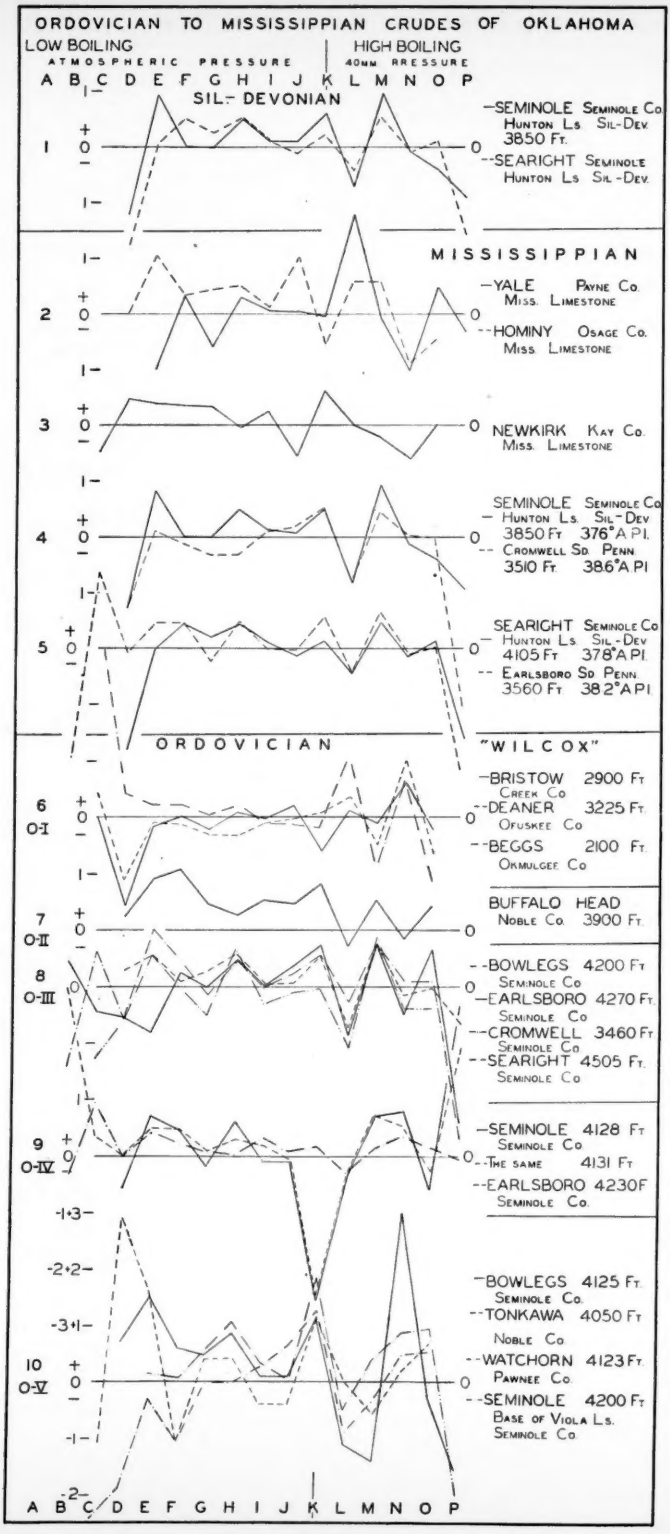
ORDOVICIAN TO MISSISSIPPIAN CRUDES OF OKLAHOMA
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM PRESSURE
A B C D E F G H I J K L M N O P
SIL- DEVONIAN
1
SEMINOLE Seminole Co.
Hunton Ls Sil-Dev.
3850 Ft.
SEARIGHT Seminole
Hunton Ls Sil-Dev.
MISSISSIPPIAN
2
YALE Payne Co.
Miss. Limestone
HOMINY Osage Co.
Miss. Limestone
3
NEWKIRK Kay Co.
Miss. Limestone
4
SEMINOLE Seminole Co.
Hunton Ls. Sil-Dev.
3850 Ft. 37.6°A.P.I.
Cromwell Sd. Penn.
3510 Ft. 38.6°A.P.I.
5
SEARIGHT Seminole Co.
Hunton Ls Sil-Dev.
4105 Ft 37.8°A.P.I.
Earlsboro Sd. Penn.
3560 Ft 38.2°A.P.I.
ORDOVICIAN
"WILCOX"
6
O-I
BRISTOW 2900 Ft
Creek Co
DEANER 3225 Ft.
Okfuskee Co
BEGGS 2100 Ft.
Okmulgee Co
7
O-II
BUFFALO HEAD
Noble Co. 3900 Ft.
8
O-III
BOWLEGS 4200 Ft
Seminole Co
EARLSBORO 4270 Ft.
Seminole Co
CROMWELL 3460 Ft
Seminole Co
SEARIGHT 4505 Ft.
Seminole Co
9
O-IV
SEMINOLE 4128 Ft
Seminole Co.
The same 4131 Ft
EARLSBORO 4230F
Seminole Co.
10
O-V
BOWLEGS 4125 Ft.
Seminole Co.
TONKAWA 4050 Ft
Noble Co.
WATCHORN 4123 Ft.
Pawnee Co.
SEMINOLE 4200 Ft
Base of Viola Ls.
Seminole Co.
-1+3-
-2+2-
-3+1-
-1-
-2-
A B C D E F G H I J K L M N O P

FIG. 5

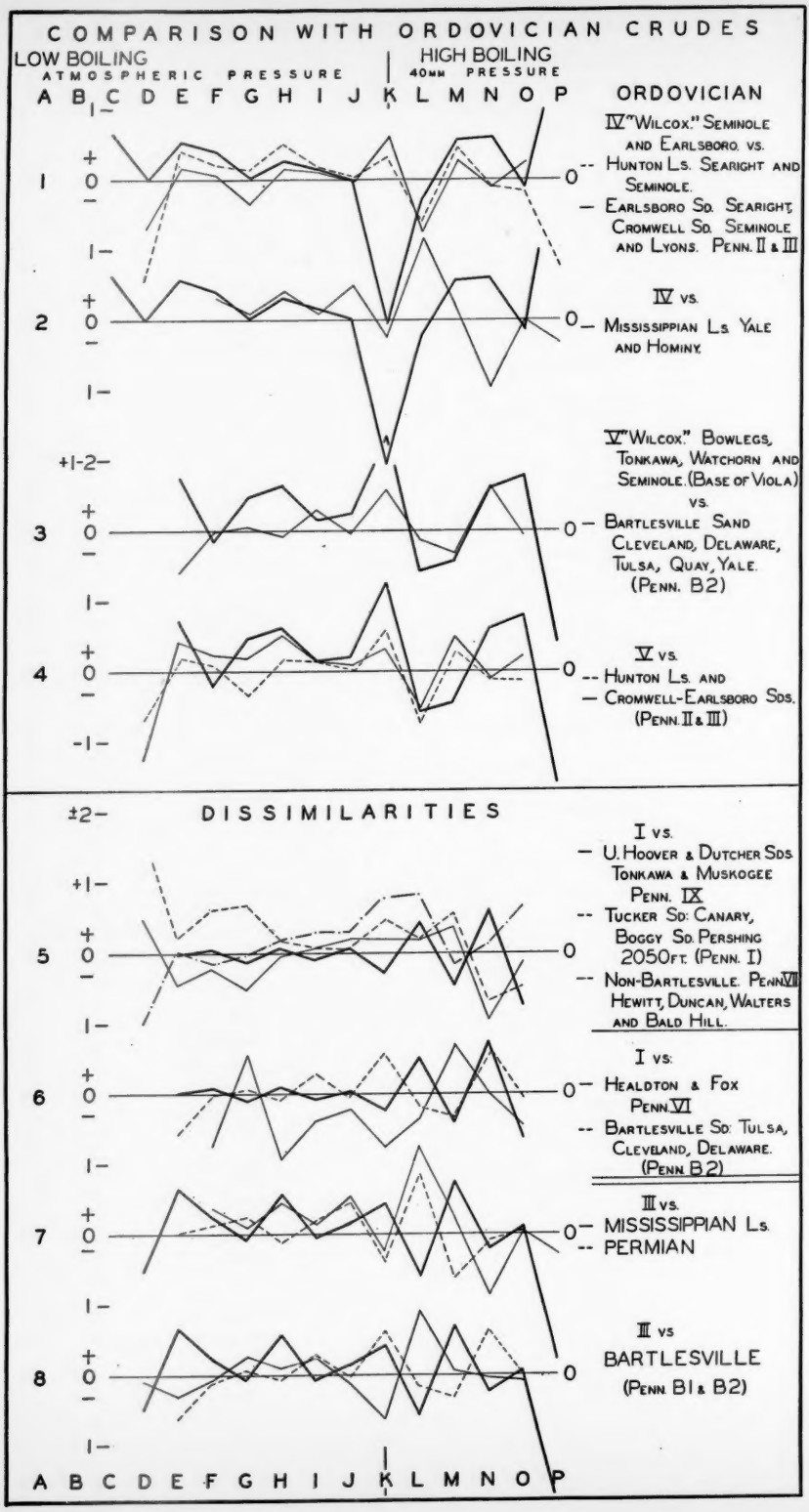
COMPARISON WITH ORDOVICIAN CRUDES
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM PRESSURE
A B C D E F G H I J K L M N O P
ORDOVICIAN
1
2
3
4
IV "WILCOX." SEMINOLE AND EARLSBORO. VS.
-- HUNTON LS. SEARIGHT AND SEMINOLE.
— EARLSBORO SD. SEARIGHT, CROMWELL SD. SEMINOLE AND LYONS. PENN. II & III
IV VS.
— MISSISSIPPIAN LS. YALE AND HOMINY.
V "WILCOX." BOWLEGS, TONKAWA, WATCHORN AND SEMINOLE. (BASE OF VIOLA)
VS.
— BARTLESVILLE SAND CLEVELAND, DELAWARE, TULSA, QUAY, YALE.
(PENN. B2)
V VS.
-- HUNTON LS. AND
— CROMWELL-EARLSBORO SDS.
(PENN. II & III)
DISSIMILARITIES
5
6
7
8
I VS.
— U. HOOVER & DUTCHER SDS. TONKAWA & MUSKOGEE PENN. IX
-- TUCKER SD: CANARY, BOGGY SD. PERSHING 2050FT. (PENN. I)
-- NON-BARTLESVILLE. PENN VII HEWITT, DUNCAN, WALTERS AND BALD HILL.
I VS:
— HEALDTON & FOX PENN. VI
-- BARTLESVILLE SD: TULSA, CLEVELAND, DELAWARE. (PENN. B2)
III VS.
— MISSISSIPPIAN LS.
-- PERMIAN
II VS
BARTLESVILLE
(PENN. B1 & B2)

FIG. 6

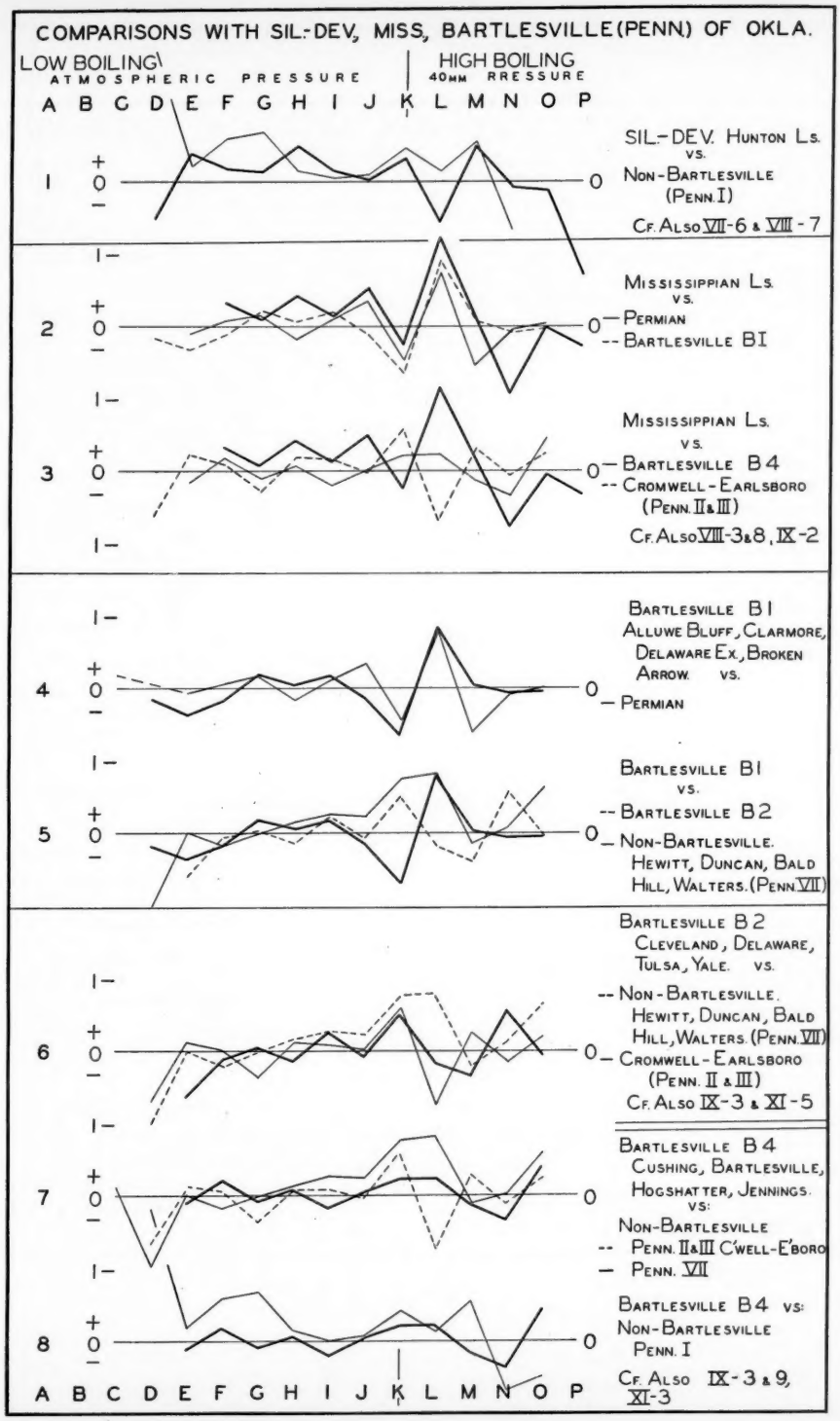
COMPARISONS WITH SIL.-DEV, MISS, BARTLESVILLE (PENN.) OF OKLA.
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM RRESSURE
A B C D E F G H I J K L M N O P
1
SIL.-DEV. HUNTON LS.
VS.
NON-BARTLESVILLE
(PENN. I)
CF. ALSO VII-6 & VIII-7
2
MISSISSIPPIAN LS.
VS.
PERMIAN
BARTLESVILLE B1
3
MISSISSIPPIAN LS.
VS.
BARTLESVILLE B4
CROMWELL-EARLSBORO
(PENN. II & III)
CF. ALSO VIII-3&8, IX-2
4
BARTLESVILLE B1
ALLUWE BLUFF, CLARMORE,
DELAWARE EX, BROKEN
ARROW. VS.
PERMIAN
5
BARTLESVILLE B1
VS.
BARTLESVILLE B2
NON-BARTLESVILLE.
HEWITT, DUNCAN, BALD
HILL, WALTERS. (PENN. VII)
6
BARTLESVILLE B2
CLEVELAND, DELAWARE,
TULSA, YALE. VS.
NON-BARTLESVILLE.
HEWITT, DUNCAN, BALD
HILL, WALTERS. (PENN. VII)
CROMWELL-EARLSBORO
(PENN. II & III)
CF. ALSO IX-3 & XI-5
7
BARTLESVILLE B4
CUSHING, BARTLESVILLE,
HOGSHATTER, JENNINGS.
VS:
NON-BARTLESVILLE
PENN. II & III C'WELL-E'BORO
PENN. VII
8
BARTLESVILLE B4 VS:
NON-BARTLESVILLE
PENN. I
CF. ALSO IX-3 & 9,
XI-3

FIG. 7

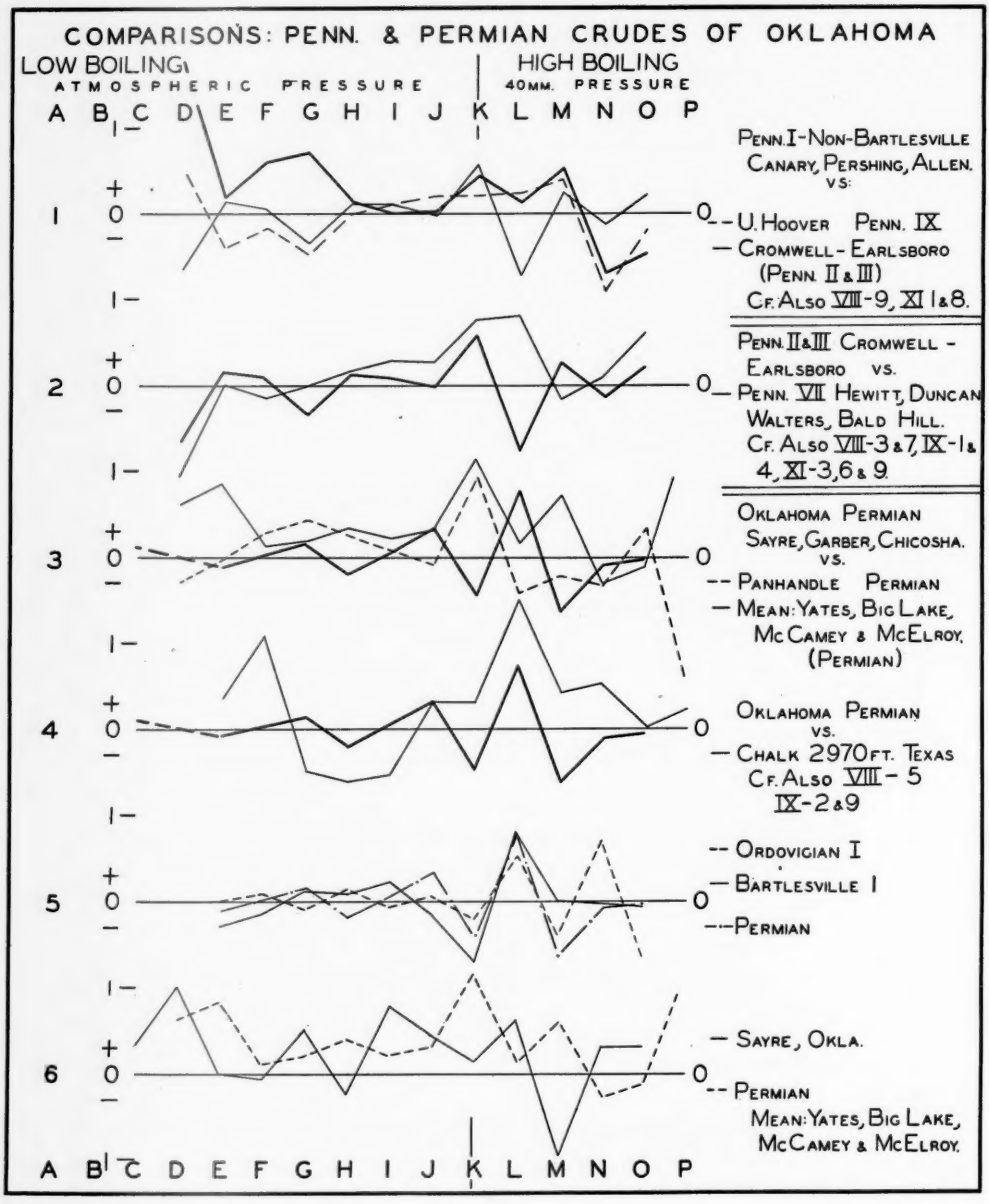
COMPARISONS: PENN. & PERMIAN CRUDES OF OKLAHOMA
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM. PRESSURE
A B C D E F G H I J K L M N O P
1
2
3
4
5
6
+
0
−
PENN. I - NON-BARTLESVILLE CANARY, PERSHING, ALLEN.
VS:
-- U. HOOVER PENN. IX
— CROMWELL - EARLSBORO (PENN. II & III)
CF. ALSO VIII-9, XI 1&8.
PENN. II & III CROMWELL - EARLSBORO VS.
— PENN. VII HEWITT, DUNCAN WALTERS, BALD HILL.
CF. ALSO VIII-3 & 7, IX-1 & 4, XI-3, 6 & 9
OKLAHOMA PERMIAN SAYRE, GARBER, CHICOSHA.
VS.
-- PANHANDLE PERMIAN
— MEAN: YATES, BIG LAKE, MC CAMEY & MCELROY. (PERMIAN)
OKLAHOMA PERMIAN
VS.
— CHALK 2970 FT. TEXAS
CF. ALSO VIII - 5
IX - 2 & 9
-- ORDOVICIAN I
— BARTLESVILLE I
--PERMIAN
— SAYRE, OKLA.
-- PERMIAN
MEAN: YATES, BIG LAKE, MC CAMEY & MCELROY.

FIG. 8

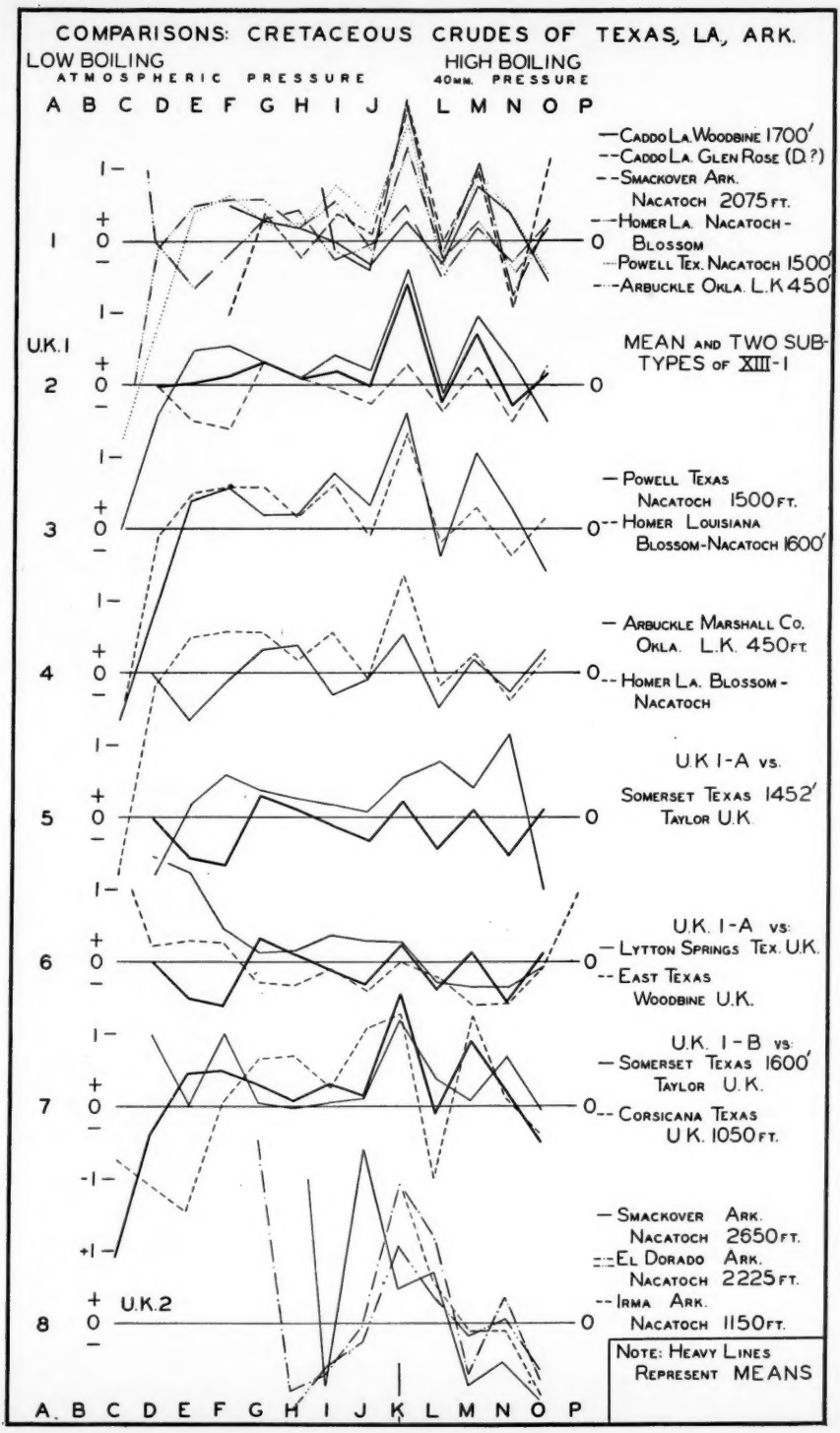
COMPARISONS: CRETACEOUS CRUDES OF TEXAS, LA, ARK.
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM. PRESSURE
A B C D E F G H I J L M N O P
—Caddo La. Woodbine 1700'
--Caddo La. Glen Rose (D.?)
- -Smackover Ark. Nacatoch 2075 ft.
- -Homer La. Nacatoch - Blossom
Powell Tex. Nacatoch 1500'
- -Arbuckle Okla. L.K 450'
1
U.K.1
2
MEAN and TWO SUB-TYPES of XIII-1
3
— Powell Texas Nacatoch 1500 ft.
--Homer Louisiana Blossom-Nacatoch 1600'
4
— Arbuckle Marshall Co. Okla. L.K. 450 ft.
--Homer La. Blossom - Nacatoch
5
U.K 1-A vs.
Somerset Texas 1452'
Taylor U.K.
6
U.K. 1-A vs:
— Lytton Springs Tex. U.K.
-- East Texas Woodbine U.K.
7
U.K. 1-B vs:
— Somerset Texas 1600'
Taylor U.K.
-- Corsicana Texas U.K. 1050 ft.
8
U.K.2
— Smackover Ark. Nacatoch 2650 ft.
- -El Dorado Ark. Nacatoch 2225 ft.
-- Irma Ark. Nacatoch 1150 ft.
Note: Heavy Lines Represent MEANS
A B C D E F G H I J K L M N O P

FIG. 9

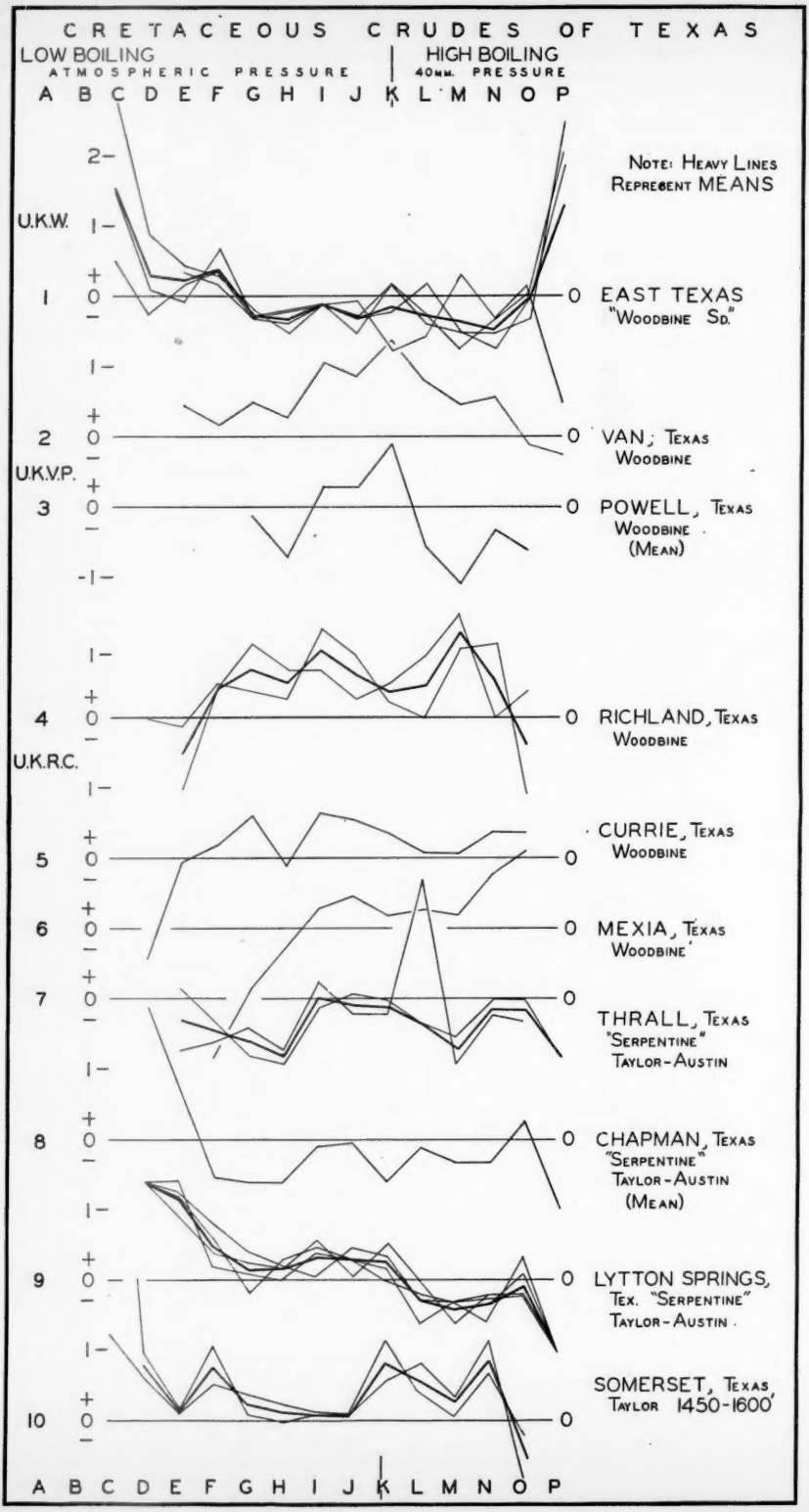
CRETACEOUS CRUDES OF TEXAS
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM. PRESSURE
A B C D E F G H I J K L M N O P
Note: Heavy Lines Represent MEANS
U.K.W.
1
EAST TEXAS "Woodbine Sd."
2
VAN, Texas Woodbine
U.K.V.P.
3
POWELL, Texas Woodbine (Mean)
4
RICHLAND, Texas Woodbine
U.K.R.C.
5
CURRIE, Texas Woodbine
6
MEXIA, Texas Woodbine
7
THRALL, Texas "Serpentine" Taylor-Austin
8
CHAPMAN, Texas "Serpentine" Taylor-Austin (Mean)
9
LYTTON SPRINGS, Tex. "Serpentine" Taylor-Austin
10
SOMERSET, Texas Taylor 1450-1600'

Fig. 10

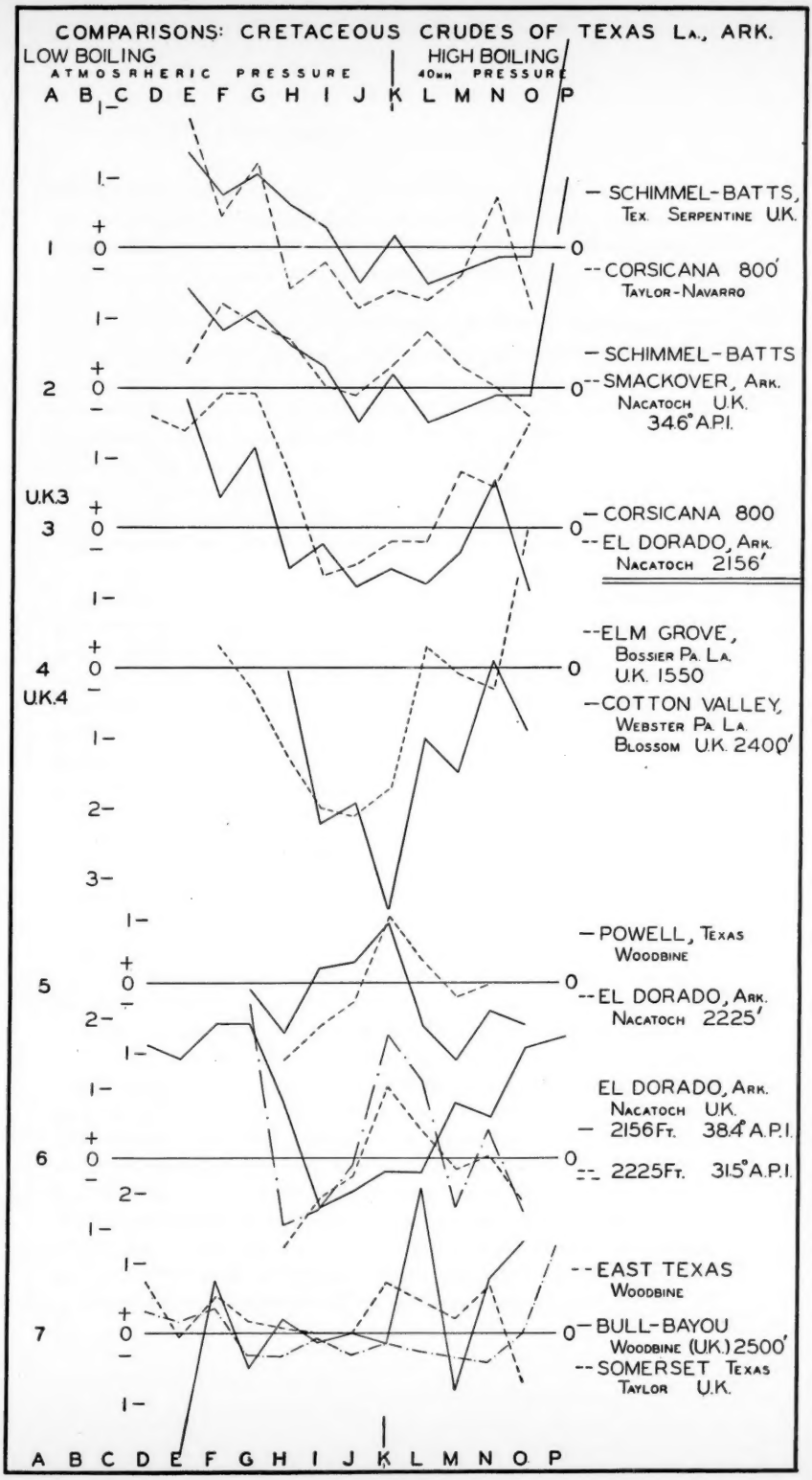
COMPARISONS: CRETACEOUS CRUDES OF TEXAS LA., ARK.
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40MM PRESSURE
A B C D E F G H I J K L M N O P
1
2
U.K.3
3
4
U.K.4
5
6
7
— SCHIMMEL-BATTS,
TEX. SERPENTINE U.K.
--CORSICANA 800'
TAYLOR-NAVARRO
— SCHIMMEL-BATTS
--SMACKOVER, ARK.
NACATOCH U.K.
34.6° A.P.I.
— CORSICANA 800
--EL DORADO, ARK.
NACATOCH 2156'
--ELM GROVE,
BOSSIER PA. LA.
U.K. 1550
—COTTON VALLEY,
WEBSTER PA. LA.
BLOSSOM U.K. 2400'
— POWELL, TEXAS
WOODBINE
--EL DORADO, ARK.
NACATOCH 2225'
EL DORADO, ARK.
NACATOCH U.K.
— 2156 FT. 38.4° A.P.I.
-- 2225 FT. 31.5° A.P.I.
--EAST TEXAS
WOODBINE
— BULL-BAYOU
WOODBINE (U.K.) 2500'
--SOMERSET TEXAS
TAYLOR U.K.

FIG. 11

practically all the products distilling up to 225°C., but the patterns were almost identical. The writer has therefore concluded that the gravity-interval pattern remains usably invariant and furnishes a satisfactory means for the comparison of crude oils.

REGIONAL STUDY OF GRAVITY-INTERVAL PATTERNS

After concluding that the gravity-interval pattern furnished a satisfactory means of comparison of various crude oils an extensive series of graphs was constructed from the Hempel analyses following the method already described. These graphs have been classified according to geographic location and geologic age of the producing beds and a series of patterns has been recognized as characteristic of crude oil of certain geologic ages and fields. The Gulf Coast graphs which were studied in considerable detail revealed more than twenty different recognized types.

Before proceeding with a description of the Gulf Coast patterns it will be helpful to review briefly some of the gravity-interval patterns for other areas which show rather striking differences both among themselves and in comparison with the Gulf Coast types. For this reason we have selected certain graphs of oils of Permian and Pennsylvanian ages from the West Texas basin area, also some representative graphs of Ordovician and Pennsylvanian crude oils from Oklahoma and a few graphs of Cretaceous oils from Texas, Arkansas, and Louisiana. These are shown in Figures 2 to 12, inclusive, and the more important characteristics and conclusions to be gathered from them are the following.

The West Texas Permian pattern (Fig. 2) is characteristic of oils from the Panhandle to the Chalk field in Howard and Glasscock counties, a distance of 400 miles. The Pennsylvanian patterns (Fig. 4) for oils of Cisco, Strawn, and Marble Falls are likewise recognized over distances of more than 100 miles. There appears to be a systematic variation in the character of the pattern from one area to another and patterns of crude oils of different ages tend to be different.

The study of graphs of Oklahoma oils (Figs. 5–8) brings out clearly the necessity for a more extensive series of analyses, including both samples from more fields and more samples from each sand in each field. The presence of radically different patterns among crude oils from a common formation, such as the "Wilcox" (Ordovician) or Bartlesville (Pennsylvanian), raises a question whether these are different crude oils, or whether the differences are the result of geographic effect upon the character of a common source material, or of conditions of petroleum accumulation, or both. The identity of a Hunton lime-

stone (Siluro-Devonian) pattern (Fig. 6) with an Ordovician pattern of the same district suggests a possible derivation of one from the other by migration. This study has not attempted to solve the problems of the relationships of Oklahoma crude oils but has merely served as a sort of reconnaissance survey.

The Cretaceous crude oils of Arkansas, North Louisiana, East Texas, and south to the San Antonio district show a rather wide va-

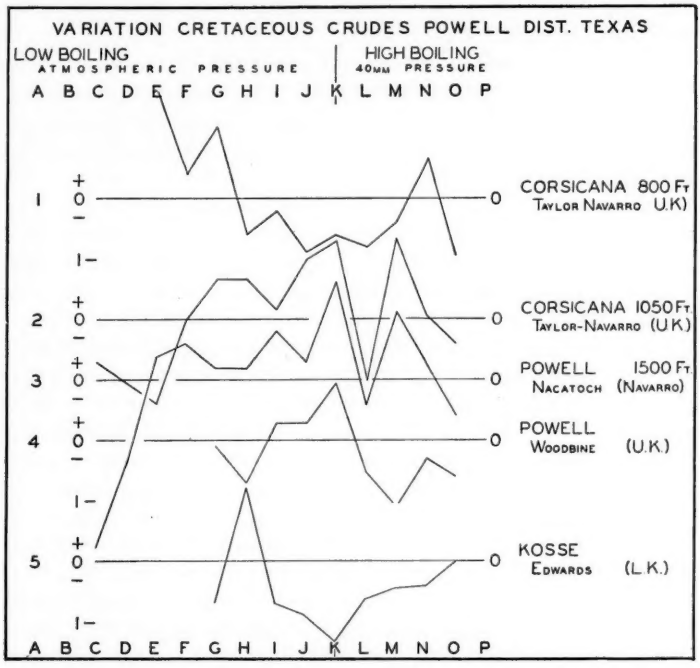

FIG. 12

riety of gravity-interval patterns (Figs. 9–12). Suggestive similarity of pattern is shown by oils of the same age but crudes of Woodbine age show variations between adjacent fields and the patterns of crude of different sands in the same field differ.

An interesting problem is presented by the three different types of gravity-interval pattern shown by Woodbine oils of the East Texas embayment (Fig. 10). The following suggestions are offered in explanation. 1. The different types are contemporaneous but the source

materials accumulated under differing conditions in different parts of the basin, causing the variation in the character of the oil. 2. The different types are derived from different source beds, that is, they may be indigenous respectively to the Woodbine sand, the overlying beds, the underlying Woodbine shales, or to any of the beds with which the Woodbine is, or has been, in fault contact. 3. The types may be of one or the other origin or may be mixtures of oils of different origins. We are inclined to regard the accumulation of different source materials under different conditions at different geologic times as the more likely explanation.

The gravity-interval patterns of crude oils of the West Texas basin, Oklahoma, and the Cretaceous oil province of Arkansas, North Louisiana, and Texas serve to outline some of the problems and possibilities in the use of this method of establishing genetic relationships, and provide a broad background for the more detailed study of the Gulf Coast crude oils. We conclude that the method has generally usable possibilities in correlating genetically related crude oils and in distinguishing between genetically unrelated crude oils, but in certain cases it gives no usable clue to relationship.

A tendency toward a common pattern is characteristic of many of the crude oils of a common age and may extend over a wide area, as in the case of the Permian pattern of West Texas or several Cretaceous patterns found both in the Powell-Corsicana district and the North Louisiana-Arkansas district. The pattern in some cases is so distinctive that it is considered as characteristic of its particular group of oils of narrow stratigraphic range and strongly suggests a close genetic relationship between the crude oils of that group. This is true, for example, of certain Nacatoch (Cretaceous) crude oils, of the Woodbine oils of the Richland-Currie, Powell, and Van (Cretaceous) fields; of a group of Cisco (upper Pennsylvanian) oils; of a group of Marble Falls (Pennsylvanian) oils; and of a group of Smithwick (Pennsylvanian) oils. Among the Oklahoma crude oils the close similarity in pattern between the Fox and Healdton samples (Pennsylvanian), between the two samples of Bartlesville (Pennsylvanian) crude from Osage County, between certain groups of "Wilcox" (Ordovician) crude, between certain other groups of Bartlesville (Pennsylvanian) crude, and between certain non-Bartlesville Pennsylvanian crudes suggests close genetic relationships between the individual members of each of those groups.

Notable differences in patterns are not uncommon between crude oils in different stratigraphic horizons in the same area or field or in

the same sand in different fields. The divergence in pattern necessarily indicates difference in molecular composition, which in turn indicates difference in the past history of the crudes and therefore strongly suggests lack of genetic relationship.

As examples we may cite the respectively different patterns of the following: the crude from 1,600–1,800 feet and the crude from 2,970 feet at Chalk; the crude from 800 feet and the crude from 1,050 feet at Corsicana; the crude from 1,500 feet (Nacatoch) and the crude from 3,300 feet (Woodbine) at Powell; the Nacatoch crude from 2,075 feet and 2,650 feet at Smackover; and the Nacatoch crudes from 2,156 feet and 2,225 feet at El Dorado. The differences in pattern in these cases and the suggestion that the members of each pair are not closely related are evidences against vertical migration. In no case could one crude be derived from the other without drastic molecular rearrangement.

The variations in pattern between groups of crudes in the same sand, for example, among the Woodbine crudes of the East Texas basin, or among the "Wilcox" Ordovician crudes of Oklahoma, present an interesting problem for future study. A close similarity in pattern between crude oils in sands of different age in a few fields suggests vertical migration. In the much faulted Seminole district similar patterns of the crude from the Hunton limestone (Siluro-Devonian) and the "Wilcox" (Ordovician) strongly suggests a migration of oil from the "Wilcox" to Hunton formations.

The wide distribution of the pattern marked by little character through the interval range *D* to *J*, with peaks at *K* and *M*, and a depression at *L*, which is recognized in crude oils of different ages in different petroleum provinces, raises important questions. From its areally and stratigraphically wide distribution the pattern may perhaps indicate a close genetic relationship between all the crude oils showing it. However, similarity in pattern must not be interpreted too certainly to indicate genetic relationship. The final determination of relationship or nonrelationship may have to await some other independently invariant criterion, for example, the microfauna, or possibly the nitrogen, phosphorous, or sulphur ratio, or content. Part of the problem is to find the reason for similarity in pattern between crude oils not genetically related. Part of the explanation may lie in the fact that the interval *K* lies between the last cut at atmospheric pressure and the first cut at 40 mm. of mercury pressure, and therefore sharp peaks or depressions would be more likely to occur there than elsewhere.

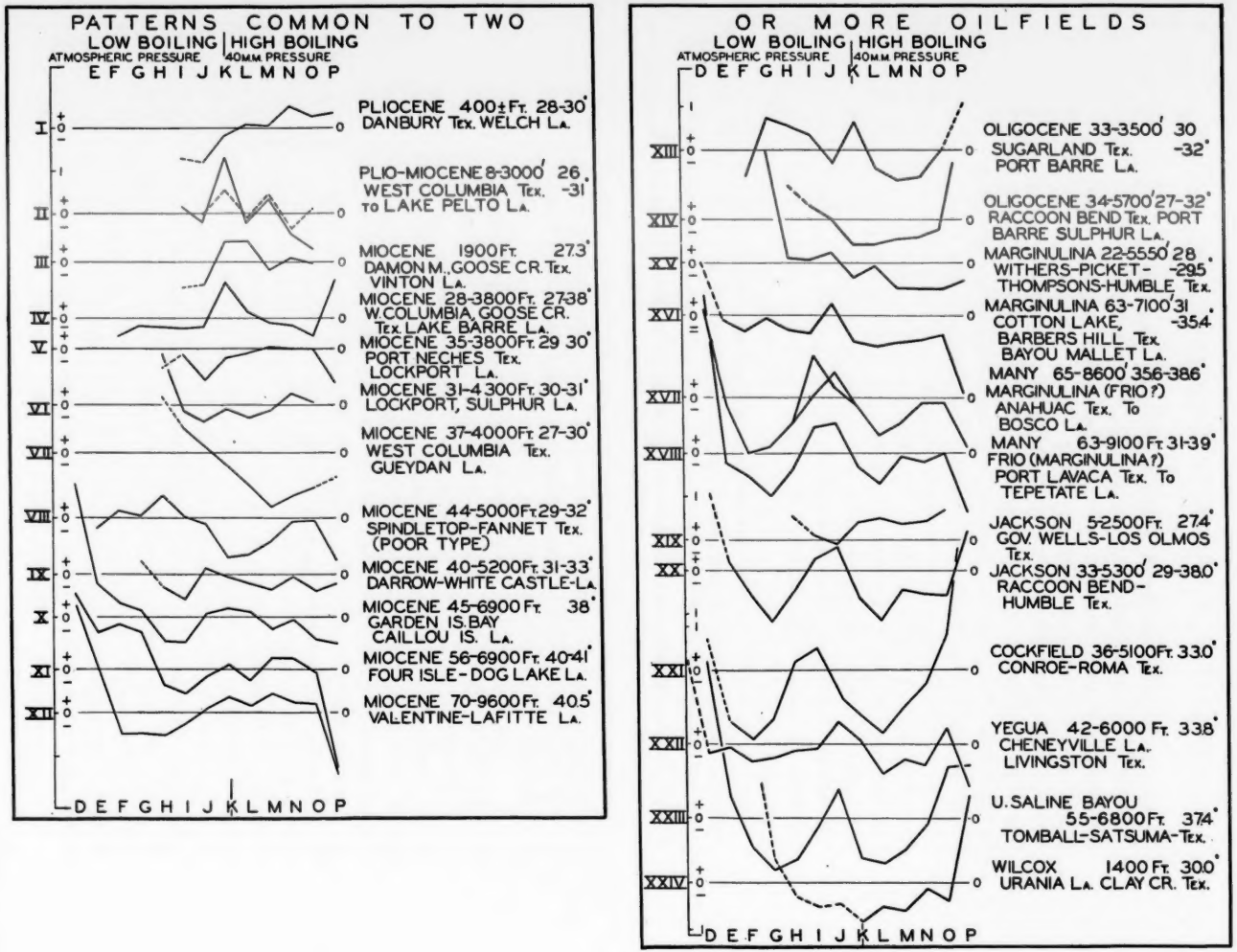
PATTERNS COMMON TO TWO OR MORE OILFIELDS
LOW BOILING | HIGH BOILING
ATMOSPHERIC PRESSURE | 40MM PRESSURE
E F G H I J K L M N O P
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
PLIOCENE 400± FT. 28-30°
DANBURY TEX. WELCH LA.
PLIO-MIOCENE 8-3000' 26°
WEST COLUMBIA TEX. -31°
TO LAKE PELTO LA.
MIOCENE 1900 FT. 27.3°
DAMON M., GOOSE CR. TEX.
VINTON LA.
MIOCENE 28-3800 FT. 27-38°
W. COLUMBIA, GOOSE CR.
TEX. LAKE BARRE LA.
MIOCENE 35-3800 FT. 29 30°
PORT NECHES TEX.
LOCKPORT LA.
MIOCENE 31-4300 FT. 30-31°
LOCKPORT, SULPHUR LA.
MIOCENE 37-4000 FT. 27-30°
WEST COLUMBIA TEX.
GUEYDAN LA.
MIOCENE 44-5000 FT. 29-32°
SPINDLETOP-FANNET TEX.
(POOR TYPE)
MIOCENE 40-5200 FT. 31-33°
DARROW-WHITE CASTLE-LA.
MIOCENE 45-6900 FT. 38°
GARDEN IS. BAY
CAILLOU IS. LA.
MIOCENE 56-6900 FT. 40-41°
FOUR ISLE-DOG LAKE LA.
MIOCENE 70-9600 FT. 40.5°
VALENTINE-LAFITTE LA.
XIII
XIV
XV
XVI
XVII
XVIII
XIX
XX
XXI
XXII
XXIII
XXIV
OLIGOCENE 33-3500' 30
SUGARLAND TEX. -32°
PORT BARRE LA.
OLIGOCENE 34-5700' 27-32°
RACCOON BEND TEX. PORT
BARRE SULPHUR LA.
MARGINULINA 22-5550' 28°
WITHERS-PICKET - -29.5°
THOMPSONS-HUMBLE TEX.
MARGINULINA 63-7100' 31°
COTTON LAKE, -35.4°
BARBERS HILL TEX.
BAYOU MALLET LA.
MANY 65-8600' 35.6-38.6°
MARGINULINA (FRIO?)
ANAHUAC TEX. TO
BOSCO LA.
MANY 63-9100 FT. 31-39°
FRIO (MARGINULINA?)
PORT LAVACA TEX. TO
TEPETATE LA.
JACKSON 5-2500 FT. 27.4°
GOV. WELLS-LOS OLMOS
TEX.
JACKSON 33-5300' 29-38.0°
RACCOON BEND-
HUMBLE TEX.
COCKFIELD 36-5100 FT. 33.0°
CONROE-ROMA TEX.
YEGUA 42-6000 FT. 33.8°
CHENEYVILLE LA.,
LIVINGSTON TEX.
U. SALINE BAYOU
55-6800 FT. 37.4°
TOMBALL-SATSUMA-TEX.
WILCOX 1400 FT. 30.0°
URANIA LA. CLAY CR. TEX.

FIG. 13

FIG. 13

GULF COAST PATTERNS

Twenty-four composite gravity-interval pattern types have been distinguished in the study of about 120 Hempel analyses of Gulf Coast crude oils.

Figure 13 shows the twenty-four types arranged in order of increasing depth and age. It is easily seen that types I and II are entirely unlike all others. There is a general similarity in southern Louisiana types and the progressive change in pattern is rather gradual up to type XVI, with more marked changes from XVII to XXIV including more exaggerated peaks.

Type I is a shallow oil of probable Pliocene age from two domes 250 miles apart (Fig. 14).

Type II is the most important Plio-Miocene type and one of the three most important Gulf Coast types. It is based on shallow Pliocene, Miocene, or cap-rock crude oils from eight domes. This distinct pattern is found all the way from West Columbia, 60 miles southwest of Houston to Lake Pelto, Louisiana, 350 miles east of Houston (Fig. 15).

Type III is a Miocene oil from depths of 1,700 to 2,000 feet at Damon Mound and Goose Creek, Texas, and Vinton, Louisiana (Fig. 14).

Type IV is also a Miocene oil, but its component patterns lack the close similarity of the three preceding types.

Types V and VI are two closely related deeper Miocene patterns based on two sets of analyses each. The depths range between 3,100 feet and 4,335 feet.

Types VII and VIII are from the deep Miocene and differ from preceding types; they are each based on two analyses.

Type IX is also a Miocene oil from salt domes at Darrow and at White Castle, Louisiana.

Types X, XI, and XII are of two patterns each from domes far south in the Mississippi delta. They are all of Miocene age.

The Oligocene types fall roughly into two groups: the first group, types XIII, XIV and XV, occurs more commonly on shallow domes and the second group, types XVI, XVII, and XVIII, is generally on very deep domes. The patterns of the first group suggest the deeper Miocene while the second group resembles the Eocene patterns.

Types XVI, XVII, and XVIII represent *Marginulina* and Frio ages.

Types XIX to XXIV are crude oils of Eocene age and generally show exaggerated patterns, but are similar to the Oligocene types.

Type XIX is composed of three patterns, two from the Jackson of Government Wells and one from the lower Eocene.

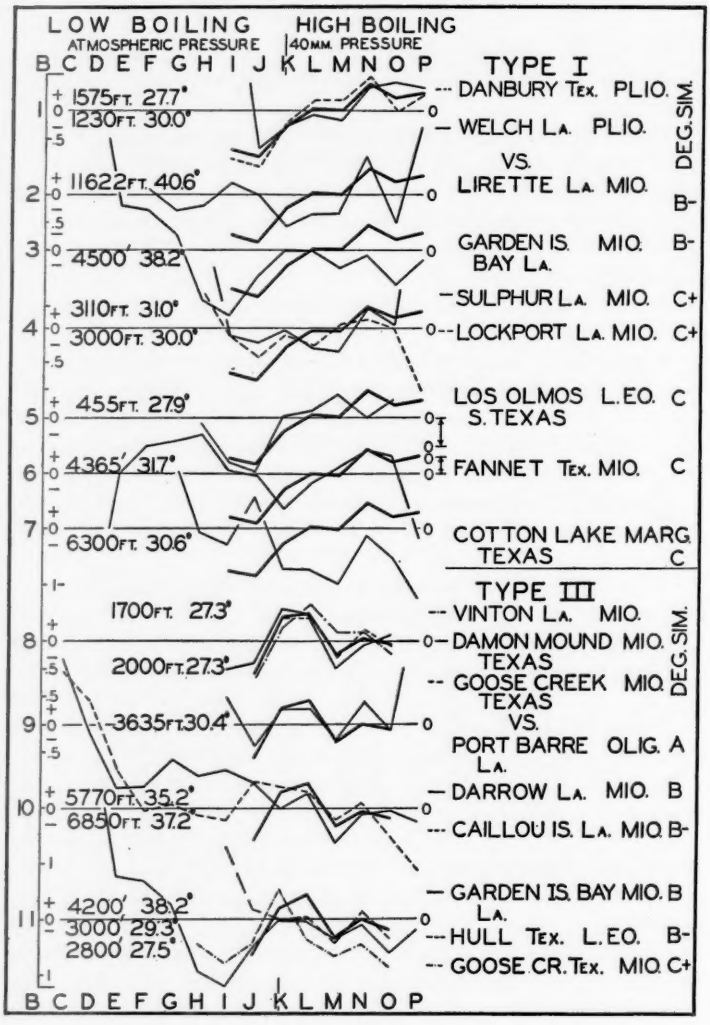

FIG. 14

Type XX is based on four patterns, three from the Jackson and one lower Eocene. This type closely resembles the Frio type XVIII (Figs. 16 and 19).

The occurrence of a common unique pattern in oils from beds of

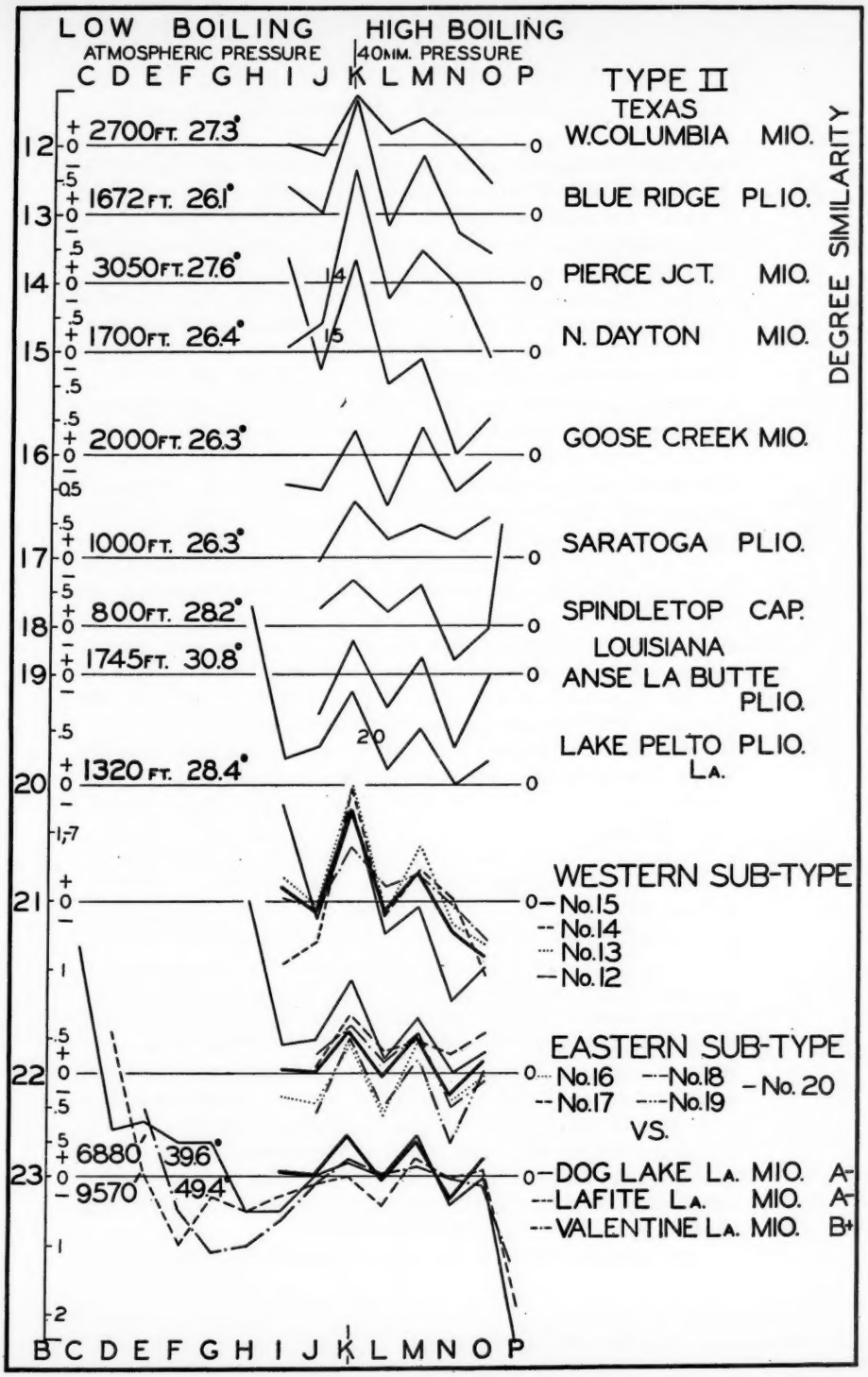
LOW BOILING
HIGH BOILING
ATMOSPHERIC PRESSURE
40MM. PRESSURE
C D E F G H I J K L M N O P
TYPE II
TEXAS
W.COLUMBIA MIO.
BLUE RIDGE PLIO.
PIERCE JCT. MIO.
N. DAYTON MIO.
GOOSE CREEK MIO.
SARATOGA PLIO.
SPINDLETOP CAP.
LOUISIANA
ANSE LA BUTTE PLIO.
LAKE PELTO PLIO. LA.
2700FT. 27.3°
1672FT. 26.1°
3050FT. 27.6°
1700FT. 26.4°
2000FT. 26.3°
1000FT. 26.3°
800FT. 28.2°
1745FT. 30.8°
1320FT. 28.4°
6880 39.6°
9570 49.4°
WESTERN SUB-TYPE
No.15
No.14
No.13
No.12
EASTERN SUB-TYPE
No.16 No.18 - No. 20
No.17 No.19
VS.
DOG LAKE LA. MIO. A-
LAFITE LA. MIO. A-
VALENTINE LA. MIO. B+
DEGREE SIMILARITY
B C D E F G H I J K L M N O P

FIG. 15

the same general geologic age in two or more adjacent oil fields is strongly suggestive of the common origin of those oils. When the similar pattern is recognized at two widely separated oil fields the evidence is less compelling. If the same pattern occurs in oils from beds of different geologic ages the inference of identity is still weaker.

The types listed, and shown in Figures 13–19, are with two exceptions based on oils from the same geologic horizon, and in many cases from adjacent oil fields, so that the assumption of a general identity of the crude oils of any given types seems warranted.

Twenty per cent of the patterns are limited to a single field and only three types can be called common and widespread.

Most of the crude oils of the Gulf Coast seem to belong more or less to that part of the stratigraphic section in which they are found to-day. Freakish patterns for certain oils are regarded as indicative of migration and associated filtration effect.

The closest affinities of the paraffine-base deep Miocene oils of the Mississippi delta are with the naphthene base Miocene oils of southwest Texas.

A roughly progressive change of pattern takes place from Eocene to Miocene and perhaps marks progressive change in the character of the source material. The effects of facies must be present but this study has not been refined enough to recognize them.

Local lensing of the source beds seems to be indicated by the very limited occurrence of most of the distinctive patterns, and this may possibly explain much of the difference in productivity of the salt-dome oil fields.

In Figures 14–19 the heavy line in each case is the *type* which is a graph of the mean value of the gravity-interval patterns. The gravity-interval pattern is represented by thin solid or dashed lines, or dashed and dotted lines, and the name of the field is written beside the symbol used. Usually a series of patterns from various fields is shown with a type graph for comparison. This permits conclusions to be drawn as to relationships between Gulf Coast crudes and also with crudes of other areas. The degree of resemblance is indicated at the right by the letters $A-$, $B+$ or $-$, C, *et cetra*, as in grading examination papers.

Pliocene type I found at Danbury, Texas, and Welch, Louisiana, is shown in Figure 14. The similarity of the two patterns comprising this type from the same stratigraphic horizon and actual depth suggests a similar origin. The other selected graphs in the upper half of this figure are compared with type I, which is superimposed upon them, but none shows close similarity.

The important Plio-Miocene type II is shown in Figure 15 which

illustrates the progressive variation from west to east and the western and eastern sub-types.

The Oligocene type XIV is found from Raccoon Bend, Texas, to Pt. Barre, Louisiana, a distance of nearly 280 miles. This pattern, shown in Figure 16, differs from the Miocene and Pliocene patterns and also from other Oligocene patterns and suggests a common crude oil at the three widely separated localities from which the samples came.

The *Marginulina*-Frio (Oligocene) type XVII is a much more important pattern and is found from Anahuac to Bosco, a distance of about 160 miles. This is shown in Figure 17 in comparison with other patterns.

The Frio type XVIII is the most important Gulf Coast pattern as far as commercial oil is concerned. This type occurs over a distance of 150 miles and is shown in Figure 18. A comparison of other patterns with type XVIII is shown in the lower part of Figure 16.

Distinctive Eocene types are shown in Figure 19. The close similarity between type XX, based on the patterns from two sands at Raccoon Bend and two sands at Humble has already been referred to and is shown on Figure 16. This suggests a possible migration of *Marginulina*-Frio oil into the Jackson formation.

The Tomball and Satsuma patterns are grouped under type XXIII shown in Figure 19. The pattern of Conroe crude, shown by a dotted line in the lowest graph of Figure 19, is distinctly different and suggests lensing of source material.

A review of these types shows that the closest similarity is between patterns from sands of much the same geologic age. The only example noted of close similarity across age divisions is in the case of types XX and XVIII.

Forty-eight of the 128 crude-oil analyses available for study show unique patterns. This is regarded as indicating that they are in part unique oils, in part modified crude oils, and in part the patterns are affected by analytical irregularities.

In studying those patterns which are unique to a single oil field and do not fall within the twenty-four types just illustrated, we find that 40 per cent have closest similarity to patterns of the same geologic age; 25–30 per cent show similarity between (a) deeper Miocene and Miocene and Oligocene patterns, (b) shallower Oligocene and Oligocene and Miocene patterns, (c) deeper Oligocene and Oligocene and Eocene patterns, and (d) shallower Eocene and Oligocene and Eocene patterns; and about 20 per cent show freakish patterns with little resemblance to other patterns.

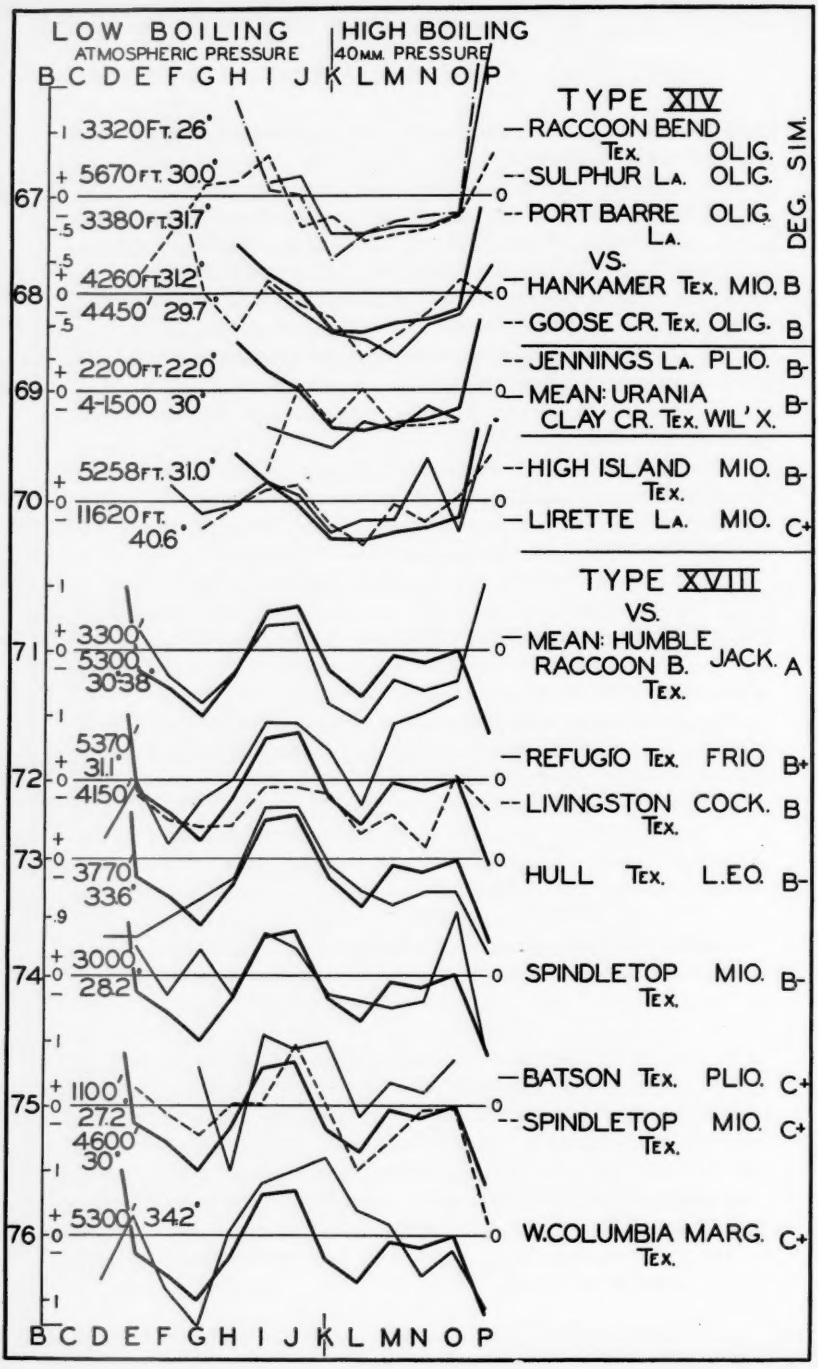
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40 MM. PRESSURE
B C D E F G H I J K L M N O P
TYPE XIV
— RACCOON BEND TEX. OLIG.
-- SULPHUR LA. OLIG.
-- PORT BARRE LA. OLIG.
VS.
— HANKAMER TEX. MIO. B
-- GOOSE CR. TEX. OLIG. B
-- JENNINGS LA. PLIO. B-
— MEAN: URANIA CLAY CR. TEX. WIL' X. B-
-- HIGH ISLAND TEX. MIO. B-
— LIRETTE LA. MIO. C+
DEG. SIM.
3320 FT. 26°
5670 FT. 30.0°
3380 FT. 31.7°
4260 FT. 31.2°
4450' 29.7°
2200 FT. 22.0°
4-1500 30°
5258 FT. 31.0°
11620 FT. 40.6°
67
68
69
70
TYPE XVIII
VS.
— MEAN: HUMBLE RACCOON B. TEX. JACK. A
— REFUGIO TEX. FRIO B+
-- LIVINGSTON TEX. COCK. B
HULL TEX. L.E.O. B-
SPINDLETOP TEX. MIO. B-
— BATSON TEX. PLIO. C+
-- SPINDLETOP TEX. MIO. C+
W. COLUMBIA TEX. MARG. C+
3300'
5300'
30.38°
5370'
31.1°
4150'
3770'
33.6°
3000'
28.2°
1100'
27.2°
4600'
30°
5300'
34.2°
71
72
73
74
75
76

FIG. 16

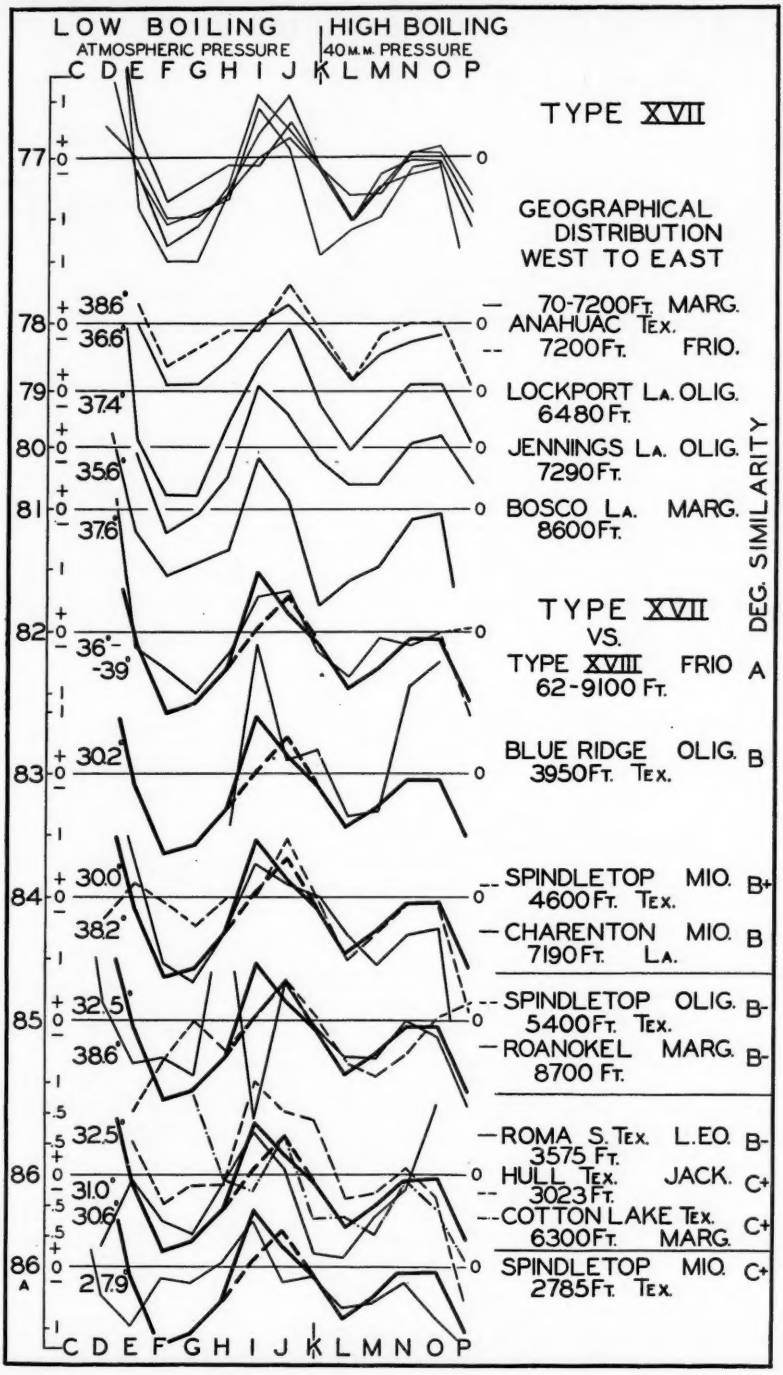
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40 M.M. PRESSURE
C D E F G H I J K L M N O P
TYPE XVII
GEOGRAPHICAL DISTRIBUTION WEST TO EAST
77
78
79
80
81
82
83
84
85
86
86 A
38.6°
36.6°
37.4°
35.6°
37.6°
36°-39°
30.2°
30.0°
38.2°
32.5°
38.6°
32.5°
31.0°
30.6°
27.9°
— 70-7200 FT. MARG. ANAHUAC TEX.
-- 7200 FT. FRIO.
LOCKPORT LA. OLIG. 6480 FT.
JENNINGS LA. OLIG. 7290 FT.
BOSCO LA. MARG. 8600 FT.
TYPE XVII VS. TYPE XVIII FRIO 62-9100 FT. A
BLUE RIDGE OLIG. 3950 FT. TEX. B
-- SPINDLETOP MIO. 4600 FT. TEX. B+
— CHARENTON MIO. 7190 FT. LA. B
-- SPINDLETOP OLIG. 5400 FT. TEX. B-
— ROANOKEL MARG. 8700 FT. B-
— ROMA S. TEX. L.EO. 3575 FT. B-
HULL TEX. JACK. 3023 FT. C+
-- COTTON LAKE TEX. 6300 FT. MARG. C+
SPINDLETOP MIO. 2785 FT. TEX. C+
DEG. SIMILARITY

FIG. 17

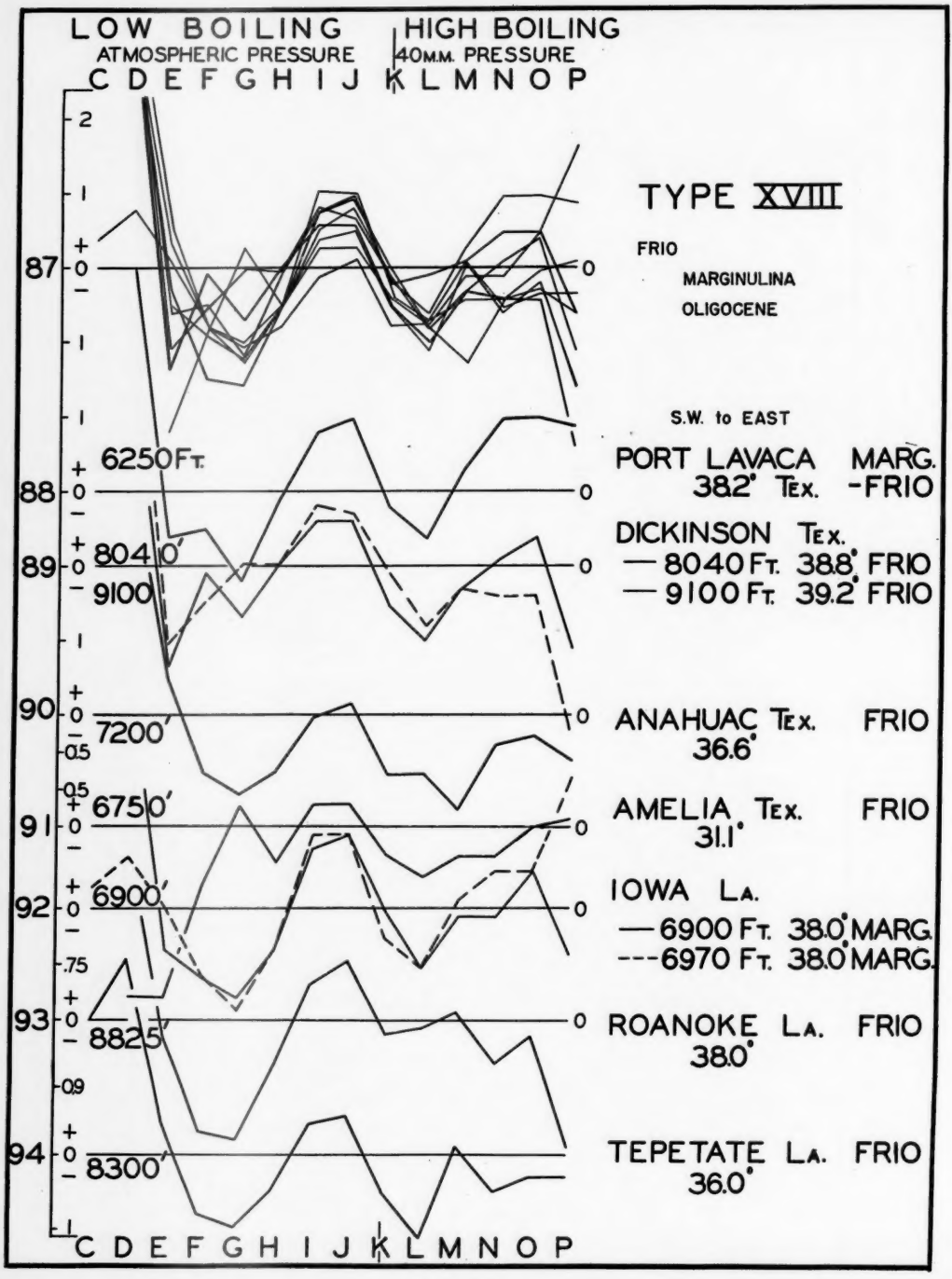
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40M.M. PRESSURE
C D E F G H I J K L M N O P
TYPE XVIII
FRIO
MARGINULINA
OLIGOCENE
S.W. to EAST
6250 Ft.
PORT LAVACA MARG.
38.2° Tex. -FRIO
DICKINSON Tex.
— 8040 Ft. 38.8° FRIO
— 9100 Ft. 39.2° FRIO
7200'
ANAHUAC Tex. FRIO
36.6°
6750'
AMELIA Tex. FRIO
31.1°
6900'
IOWA La.
— 6900 Ft. 38.0° MARG.
--- 6970 Ft. 38.0° MARG.
8825'
ROANOKE La. FRIO
38.0°
8300'
TEPETATE La. FRIO
36.0°

Fig. 18

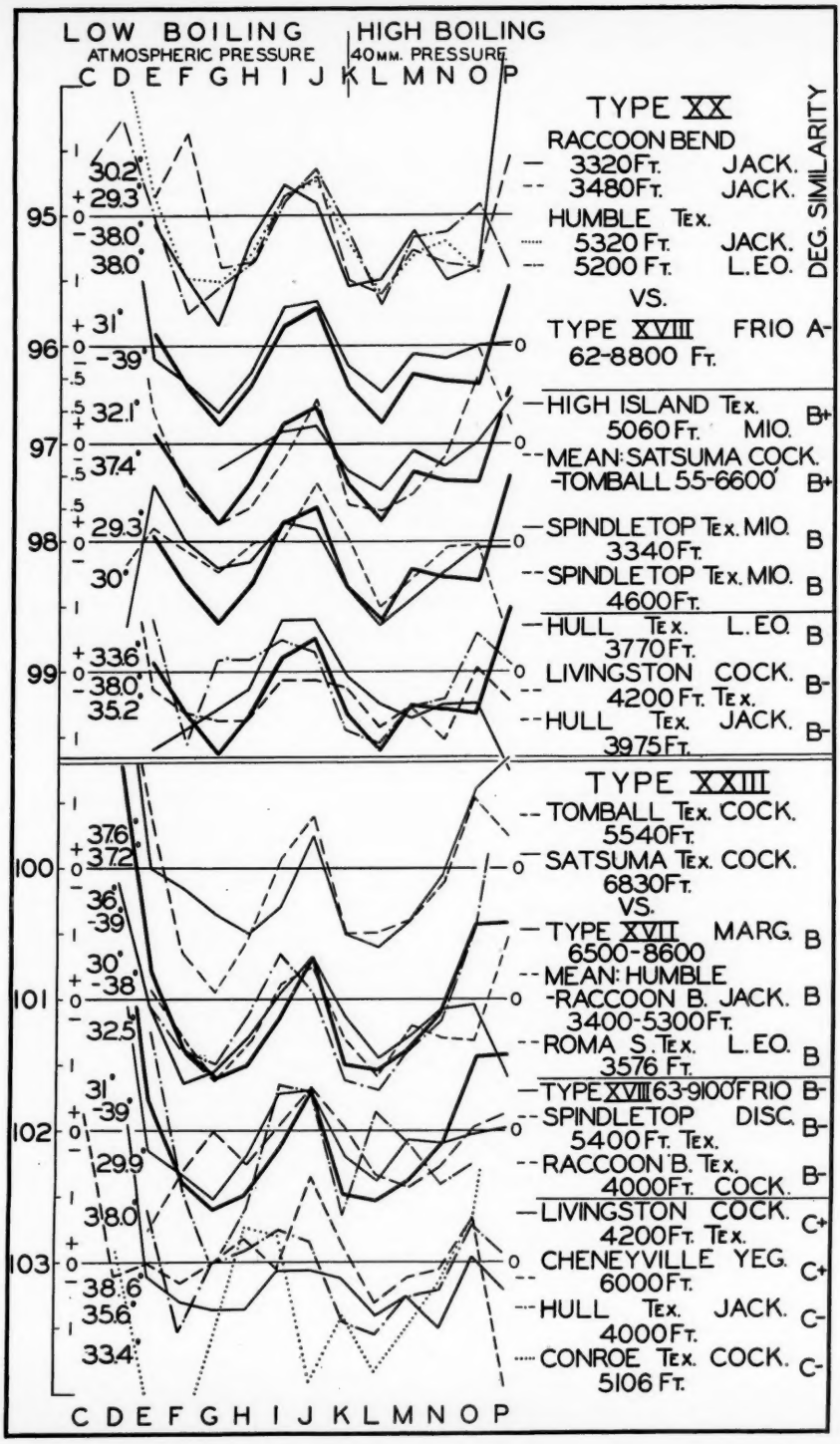
LOW BOILING
ATMOSPHERIC PRESSURE
HIGH BOILING
40 MM. PRESSURE
C D E F G H I J K L M N O P
TYPE XX
RACCOON BEND
— 3320 FT. JACK.
-- 3480 FT. JACK.
HUMBLE TEX.
..... 5320 FT. JACK.
--- 5200 FT. L.EO.
VS.
TYPE XVIII FRIO A-
62-8800 FT.
DEG. SIMILARITY
—HIGH ISLAND TEX. 5060 FT. MIO. B+
--MEAN: SATSUMA COCK. -TOMBALL 55-6600' B+
—SPINDLETOP TEX. MIO. 3340 FT. B
--SPINDLETOP TEX. MIO. 4600 FT. B
—HULL TEX. L.EO. 3770 FT. B
LIVINGSTON COCK. 4200 FT. TEX. B-
--HULL TEX. JACK. 3975 FT. B-
TYPE XXIII
--TOMBALL TEX. COCK. 5540 FT.
—SATSUMA TEX. COCK. 6830 FT.
VS.
—TYPE XVII MARG. 6500-8600 B
--MEAN: HUMBLE -RACCOON B. JACK. 3400-5300 FT. B
--ROMA S. TEX. L.EO. 3576 FT. B
—TYPE XVIII 63-9100 FRIO B-
--SPINDLETOP DISC. 5400 FT. TEX. B-
--RACCOON B. TEX. 4000 FT. COCK. B-
—LIVINGSTON COCK. 4200 FT. TEX. C+
CHENEYVILLE YEG. 6000 FT. C+
---HULL TEX. JACK. 4000 FT. C-
..... CONROE TEX. COCK. 5106 FT. C-
95
96
97
98
99
100
101
102
103
30.2°
+29.3°
-38.0°
38.0°
+31°
-39°
32.1°
37.4°
29.3°
30°
+33.6°
-38.0°
35.2°
37.6°
37.2°
36°
-39°
30°
-38°
32.5°
31°
-39°
29.9°
38.0°
38.6°
35.6°
33.4°

FIG. 19

Although the respective patterns and A.P.I. gravities of key fraction No. 1 are closely alike in the case of many crude samples from different sands in the same field, strong differences in pattern have also been noted in the patterns of some oils from sands not necessarily stratigraphically far apart.

SUMMARY

In this presentation of the gravity-interval pattern as a standard for comparing crude oils it is shown how a graph of the gravity-interval pattern is compiled from the Hempel analyses and how by comparison of these graphs a series of types has been identified which is a mean of several graphs. The types are represented always by heavy solid lines in the figures and are used for comparison with patterns of individual crude oils.

We believe that the graphs shown in the text figures illustrate the distinctive and individual characteristics of the patterns of oil of different geologic ages. Generally close agreement is shown by oils of the same age from near-by fields and usually less resemblance is seen between oils of different ages and oils from fields separated by greater distances.

We believe that this is a useful method of comparison of crude oils and feel that close relationship and possible identity are indicated by closely similar patterns. We realize there are many factors which affect the pattern and that variations in the accuracy of the analyses as well as the relatively small number of analyses available for most of the crudes should be given due consideration. Our conclusions are therefore to be regarded as of a preliminary nature. As more Hempel analyses become available it is hoped that the gravity-interval pattern may be further studied and tested so that its true value as a means of identifying and correlating crude oils may be established.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 4 (APRIL, 1941), PP. 593-629, 16 FIGS.

NORTH COWDEN FIELD, ECTOR COUNTY, TEXAS[1]

SAM C. GIESEY[2] AND FRANK F. FULK[3]
Midland and Tyler, Texas

ABSTRACT

Geographically, the North Cowden field is on the transition between the Llano Estacado at the north and the Edwards Plateau at the south. Geologically, it is on the eastern margin of the Central Basin platform. The presence of a structure was indicated by subsurface data, and the discovery well was completed by the Southern Crude Oil Purchasing Company in September, 1930. The producing structure is an anticline 7½ miles long, with about 100 feet of closure indicated by present control. Oil is obtained from sands and limestone of lower Whitehorse age, and production is most prolific on the east, or basinward, flank of the structure—a condition due, at least in part, to the thickening of sands basinward from the crest. The first "pay" is reached at an average depth of 4,027 feet, and the average amount of pay section penetrated is 89 feet. A gas cap exists in the first pay zone on the higher parts of the structure. Progressive folding during Whitehorse and Salado time moved the axis of the structure basinward. Post-Rustler movement shifted it about 1¼ miles west to its present position. The present productive area of the field includes 9,760 acres.

The Cowden anhydrite is defined in this paper.

INTRODUCTION

In this paper the North Cowden field is described as of September, 1938. Subsequent developments, consisting mainly of an eastward extension and the discovery of the deep "Holt pay," are not discussed.

LOCATION

The North Cowden field is on the eastern margin of the Central Basin platform. It is in north-central Ector County, Texas, 18 miles by highway north and west of Odessa, the county seat, and 30 miles northwest of Midland. A paved highway connecting United States Highway 80 with the Texas Panhandle parallels the field 5 miles east. The field is intersected both longitudinally and laterally by graded roads.

HISTORY

The site of the North Cowden field attracted major oil companies in 1924 and 1925. Leasing was carried on slowly and without any semblance of a boom. The Southern Crude Oil Purchasing Company obtained the largest single block in October, 1925, by leasing the J. M. Cowden Estate, which contains 3,200 acres. At the time the original 10-year leases were taken, there were no producing wells closer than the Big Lake field, Reagan County, approximately 125 miles southeast. Many of the major operators in West Texas during the interval

[1] Read before the Association at El Paso, September 30, 1938. Published by permission of the Stanolind Oil and Gas Company. Manuscript received, September 2, 1940.

[2] Geologist, the Union Oil Company of California.

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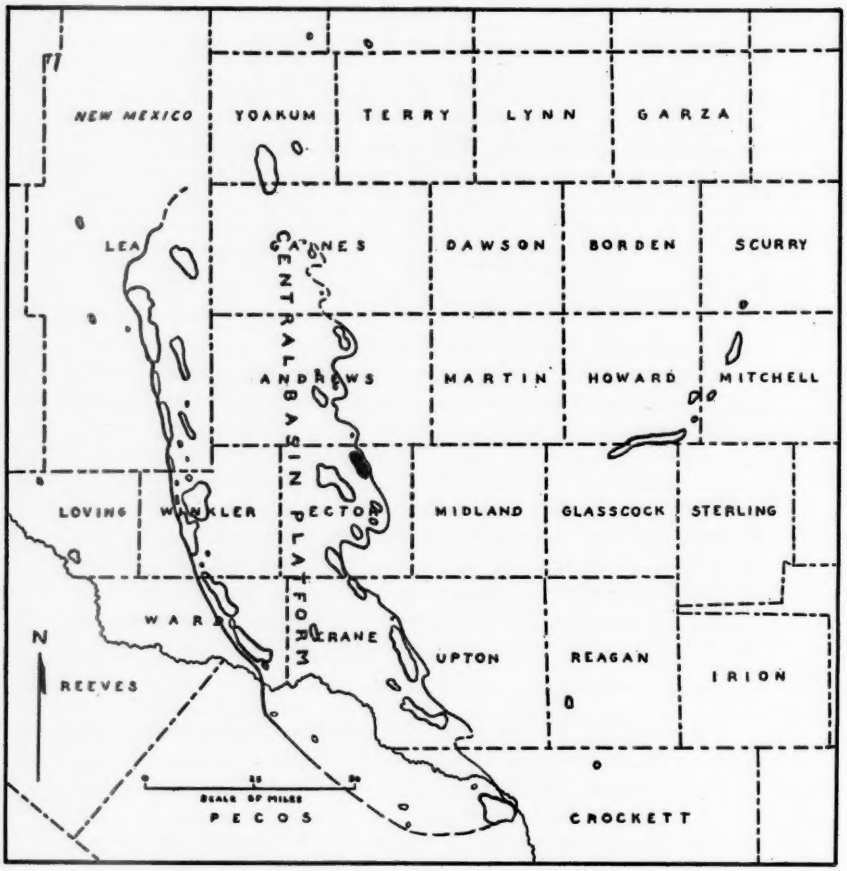


FIG. 1.—Regional position of North Cowden field (shown in solid black).

from 1923 to 1928 purchased spreads of leases in many West Texas counties. Few of these wildcat leases cost more than 2 dollars bonus per acre.

The discovery well in the North Cowden field was the Southern Crude Oil Purchasing Company's (now Stanolind Oil and Gas Company) J. M. Cowden No. 1. This well is located near the center of the Stanolind Oil and Gas Company block and approximately one mile north of the geographic center of the field. It was spudded on May 29, 1930, drilled with a standard rig, and completed on September 11, 1930, with a natural daily flow of 272 barrels. On January 16, 1934, it was shot with 160 quarts of nitroglycerine. Immediately following this shot, the well received a new proration potential of 777 barrels daily.

Upper waters necessitated the running of four strings of pipe in the cable-tool discovery well: 15¼-inch at 136 feet (cemented), 12⅛-inch at 1,035 feet (mudded), 11-inch at 1,787 feet (cemented), and 8¼-inch at 3,957 feet (cemented). A sand member, capable of producing one barrel of salt water hourly, was encountered between 3,670 and 3,675 feet in the Queen sand.

The Southern Crude Oil Purchasing Company's J. M. Cowden No. 2-A, ¾ mile southwest of the discovery, was spudded in October, 1930, and completed in April, 1931. This well encountered fresh water at 90–100 feet, 150–160 feet, and a hole full at 190–200 feet, and brackish water from 1,120 to 1,130 feet. A string of 10-inch casing was cemented in the Rustler anhydrite at a depth of 1,803 feet and salt water, which rose to 400 feet, was encountered at 1,860–1,865 feet. It was necessary to employ a Halliburton cementing truck to force 200 sacks of cement under a pressure of 1,050 pounds per square inch into the water zone in order to kill the flow of water. In the Queen sand at 3,680–3,686 feet salt water was encountered in such quantities that the well actually flowed 40 barrels daily. It was necessary for the operators to drill the next 300 feet with a hole full of salt water in order to avoid running a long string of pipe. The numerous and erratic water-bearing strata found in the first two wells convinced the Southern Crude Oil Purchasing Company that cable-tool drilling from the surface to the top of the limestone was less efficient than rotary drilling.

Owing to the absence of a pipe-line outlet, active drilling and development of the field were deferred for approximately 3 years after the completion of the Southern Crude Oil Purchasing Company's J. M. Cowden No. 2-A. During the period of flush production in the Mid-Continent from January, 1931, to January, 1934, only seven wells were drilled. The Landreth Production Company's O. B. Holt No. 1,

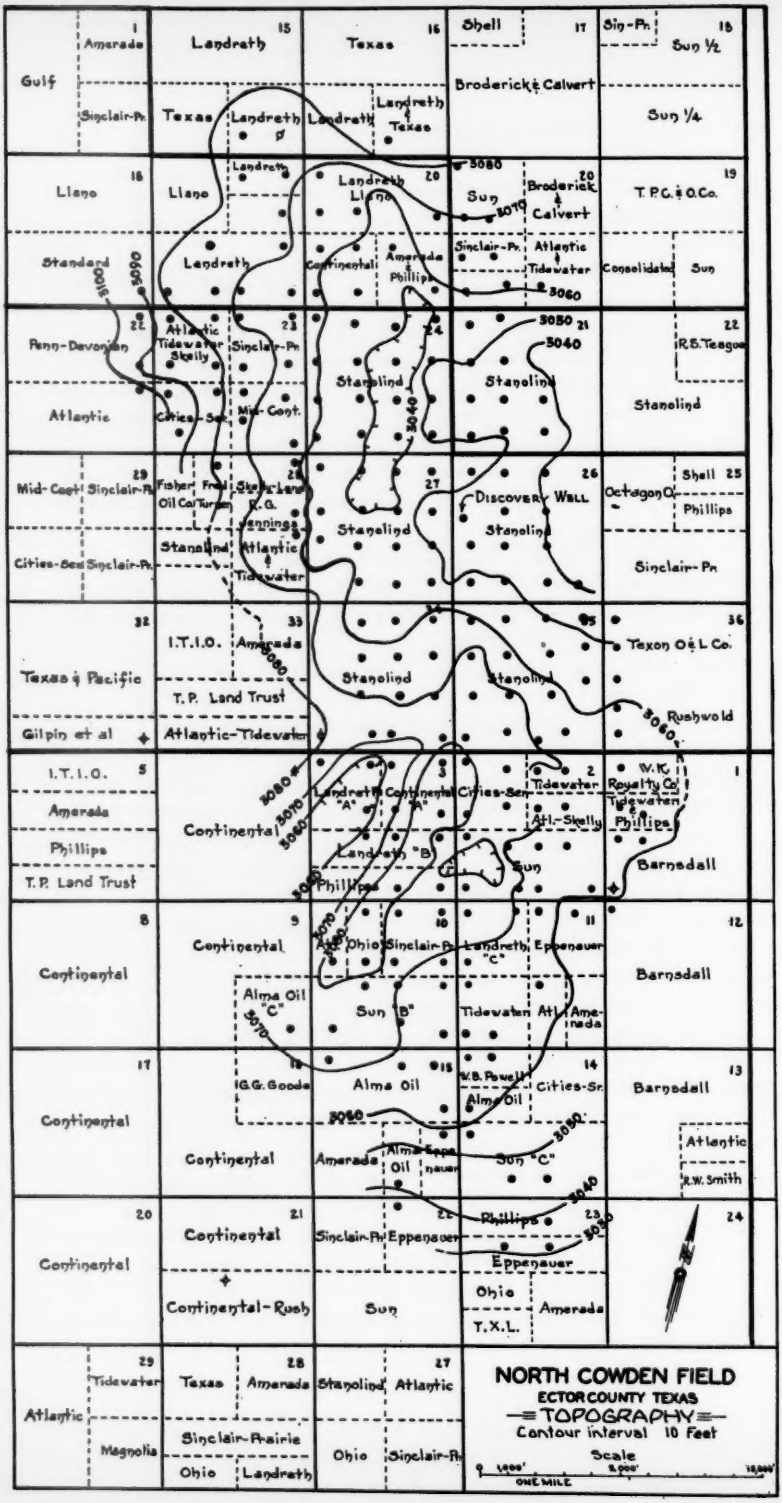


FIG. 2.—Topography sketched from well elevations.

in the center of the SW. ¼, SE. ¼ of Sec. 15, Block 43, T. 1 N., T. & P., was spudded in the latter part of 1932 and completed in March, 1933. This well, drilled about 3 miles northwest of the discovery well, marks the northwest limit of production in the field at the present time (September, 1938). A second outpost well, the Barnsdall Oil Company's R. W. Smith No. 1, was located 3 miles southeast of the discovery. An initial production of 42 barrels of oil per day pumping, after being shot, definitely limited exploration in the immediate vicinity of this well. A third well, Frank Gilpin *et al.* Blakeney No. 1-A, Sec. 32, Block 43, T. 1 N., approximately 3 miles southwest of J. M. Cowden No. 1, was abandoned when it failed to produce more than 5 barrels of oil daily after being shot.

The Landreth Production Company's T. & P. Land & Trust No. 1-A, in the north part of Sec. 3, Blk. 43, T. 1 S., was the second milestone in the development of the North Cowden field. The well was completed, having a daily potential production of 808 barrels after being shot. This resulted in a drilling campaign in a southeasterly direction which eventually extended the field 3 miles. The Devonian Oil Company's Blakeney No. 1, in Sec. 22, Blk. 43, T. 1 N., although a small well, was directly responsible for the drilling of sixteen additional wells in the northwest part of the field. Fred Turner's Blakeney No. 1, drilled ½ mile south and ½ mile east of the Devonian Oil Company's well, retarded development on the west side of the field. This well had an initial production of 90 barrels of oil daily with an abnormally high gas-oil ratio, which eventually led to its being produced as a gas well.

The greatest development of the North Cowden field occurred during 1936 and 1937. The period began with 61 wells producing a total of 3,625 barrels of oil per day and ended with 187 wells producing 6,520 barrels per day. The first 61 wells completed had a combined daily potential of 35,482 barrels and the 127 wells completed during the flush period added 76,862 barrels to the field's daily potential. During the first half of 1938 twenty-four wells were completed, and the daily field potential raised to 128,177 barrels.

The Standard Oil Company of Texas' Cochran No. 1, located in Sec. 18, Blk. A, P. S. L., is the farthest northwest well. Structurally, it is definitely on the west flank of the "high," and it is the only commercial well in the field which is unreservedly conceded to be so situated. The pay section in this well contained 50 per cent more sand than did either of its offsets, and the sands showed less anhydritic and dolomitic cementation than the equivalent sands in the offsets.

On July 1, 1938, there were 208 producers and four dry holes within the designated bounds of the North Cowden field. The wells drilled

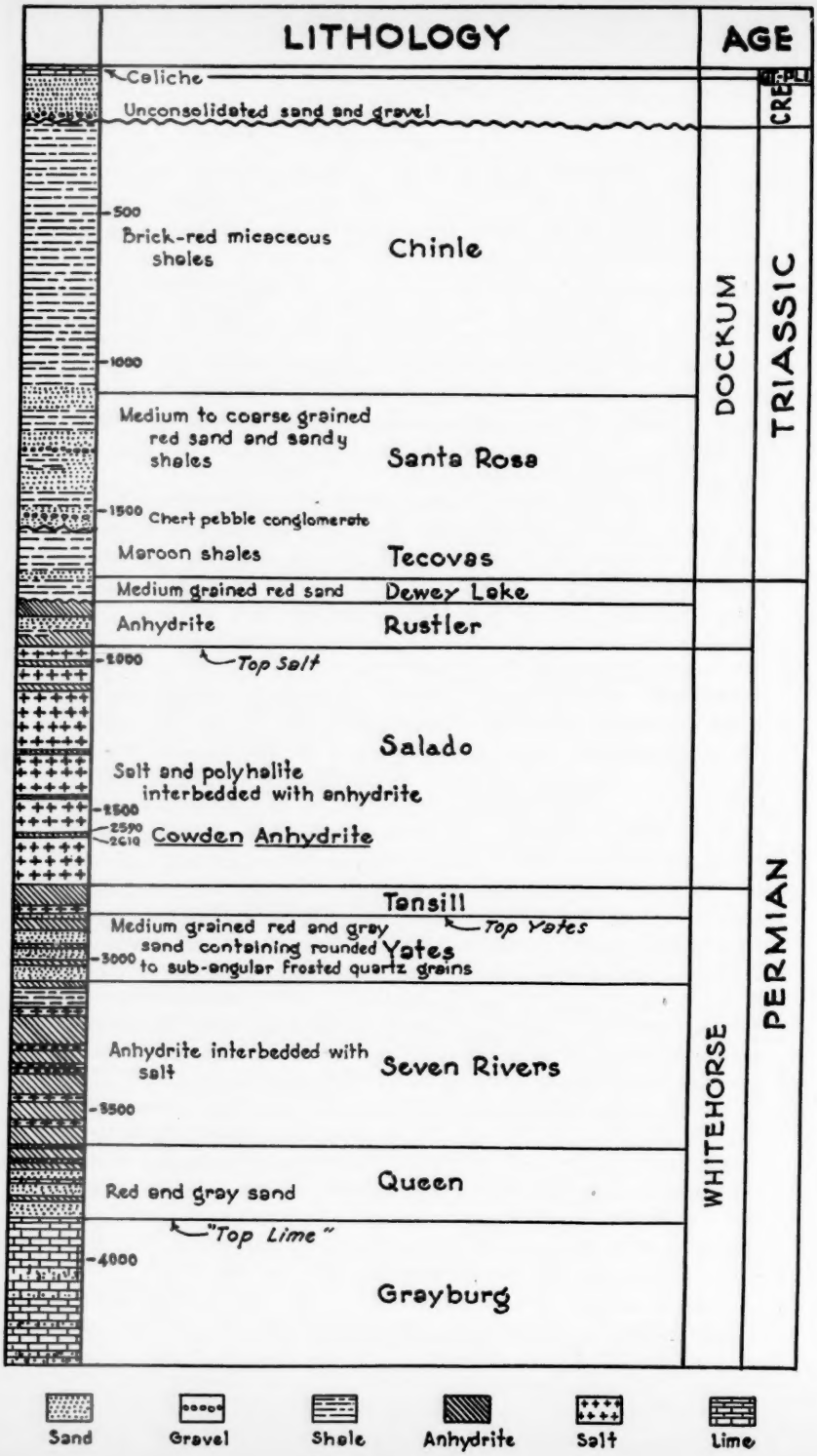


FIG. 3.—Type section.

subsequently in Secs. 25 and 36, Blk. 43, T. 1 N., and Sec. 1, Blk. 43, T. 1 S., penetrated only two of the four zones present farther west; however, in general their potentials were twice that of the field average.

STRATIGRAPHY

The sequence of formations in the North Cowden field is typical, except for differences due to local and regional thinning and thickening of beds, of all fields on the eastern margin of the Central Basin platform. The type section for the field (Fig. 3) is composite and is based largely on the sample records of the discovery well and the Southern Crude Oil Purchasing Company's J. M. Cowden No. 2. Refinements suggested by data compiled from microscopic examination of cuttings from other cable-tool wells, of available rotary cuttings, and of plotted drilling-time records of rotary wells are included. Local thinning of Permian formations from the flanks to the crest of the structure causes the depths to the tops of formations to be somewhat greater on the flanks, and less near the axis of the structure than the depths assigned in the type section.

The following description is from the surface downward, as the section is penetrated by the drill. A detailed lithologic description is not attempted.

QUATERNARY

The surface of the North Cowden area is covered with a thin layer of wind-blown sand immediately overlying a sandy surface limestone —caliche. About 40 feet of caliche is encountered over most of the field. It is ordinarily gray to buff in color, is almost everywhere sandy, and in places contains beds of chert. Its origin is probably chemical, the evaporation of ground water having caused the precipitation of calcium carbonate and silica near the surface.

CRETACEOUS

Although Comanche limestones capping "basement" sands form a prominent west-facing escarpment in Concho Bluffs 15 miles southwest of the field, no Cretaceous limestone is present in the North Cowden section. About 100 feet of "basement" sand is, however, present below the caliche cap. This is a white to buff, coarse-grained, poorly consolidated, friable quartz sand containing several beds of chert pebbles. Potable water was encountered by the discovery well in the top of this sand and also near the middle and at the base. At or near the base of the formation a pebble bed is ordinarily found, suggestive of a basal conglomerate.

TRIASSIC

The Triassic beds of the North Cowden section consist of three formations of the Dockum group: the Chinle shale, the Santa Rosa sandstone, and the Tecovas shale.

Chinle shale.—In the type section the Chinle shale is represented as extending from 150 to 1,100 feet. It is dark red, micaceous shale, arenaceous near the top and base, and contains several lenticular beds of red sand. The Chinle is easily drilled with rotary equipment, but caves badly, so that rotary cuttings from the lower Whitehorse dolomite, 3,000 feet below, are commonly much contaminated with red shale cavings. The discovery well encountered a hole full of water from a sand bed in the Chinle at a depth of 370 feet.

Santa Rosa sandstone.—The Santa Rosa sandstone extends from 1,100 to 1,565 feet on the section, but the thickness appears to vary somewhat throughout the area. In the Southern Crude's Cowden No. 2 the thickness is as shown on the section. The formation consists principally of medium- to coarse-grained, micaceous red sands interbedded with sandy shales lithologically similar to those of the overlying Chinle. The sand grains are sub-rounded to angular, the predominant mineral being quartz. Although most of the grains are polished, some are slightly frosted. The Santa Rosa sands are poorly cemented, much of the cementing material being red clay which is largely the cause of the red color of the sandstone. The porous Santa Rosa sand is an excellent water reservoir; the discovery well logged a showing at 1,130 feet, near the top of the formation, and a hole full of water at 1,290, at 1,470, and also at 1,515 feet.

Tecovas formation.—The base of the Santa Rosa sandstone is placed at 1,565 feet on the section, and from this depth to 1,715 feet the discovery well penetrated a dark red shale section lithologically similar to the shales within the Santa Rosa and to the Chinle shales above. The Tecovas contains several thin beds of red sand which, like the shale, resemble the sands of the overlying Triassic formations. The presence of an unconformity between the Tecovas formation and the subjacent sands and sandy shales of the Dewey Lake can not be determined. There is apparently no conglomerate at the base of the Tecovas.

PERMIAN

Dewey Lake formation.—The youngest Permian formation encountered in the North Cowden field is the Dewey Lake, extending from 1,715 to 1,800 feet on the type section. The formation consists principally of medium-grained red sand, with some interbedded sandy shales. The sands of the Dewey Lake are finer-grained than those of

the overlying Triassic formations and the grains are of uniform size as contrasted with the rather poorly sorted, coarse-to-fine grains of the Santa Rosa and Tecovas. Small amounts of gypsum are ordinarily found in the Dewey Lake sands. In places near the base of the formation, quantities of large, rounded frosted sand grains are encountered.

Rustler formation.—The Rustler formation in North Cowden field consists of from 150 to 275 feet of anhydrite, salt and red sand. On the section it is depicted as extending from 1,800 to 1,950 feet, but the thickness of the Rustler varies more than any other formation in the section. In general, it may be said that the Rustler is thinner over the crest of the structure, although some structurally high wells encounter a fairly thick Rustler section. Several reasons may be advanced to account for this variation in thickness: the top of the formation may not have been uniformly removed by post-Rustler erosion, or the section may have slumped erratically subsequent to solution of the salt beds, or perhaps a combination of the two processes is responsible for the condition. The closure mapped on the top of the anhydrite in the east-central part of the field (Fig. 4) is probably due to such variations in thickness.

The contact between the overlying red clastics and the Rustler anhydrite is the familiar "Top anhydrite" marker long in use in the Wext Texas Permian basin as the first key horizon penetrated by the drill. In many places the "Top anhydrite" contours reveal in general the position of the Whitehorse beds below, and this, together with the fact that the first anhydrite is ordinarily recognized without difficulty in cuttings, makes it one of the most important markers in the section.

Although the Rustler formation includes limestone members in other localities, limestone has been observed in the Rustler section in only one well in the North Cowden field. This is brown, slightly sandy limestone, readily effervescent in cold acid. The fact that no other well has encountered such limestone makes it doubtful that this is a sample of limestone in place.

Salado formation.[4]—The Salado formation in the North Cowden field consists of 800–900 feet of salt broken by a few beds of anhydrite. Polyhalite is commonly found associated with the salt and anhydrite, and some thin beds of red sand are found in the upper part of the formation. In the discovery well the Salado extends from 1,920 to 2,785 feet. The top of the formation consists of about 30 or 40 feet of anhydrite immediately overlying the salt section. The remainder of the

[4] Walter B. Lang, "Salado Formation of the Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 10 (October, 1939), pp. 1569–72.

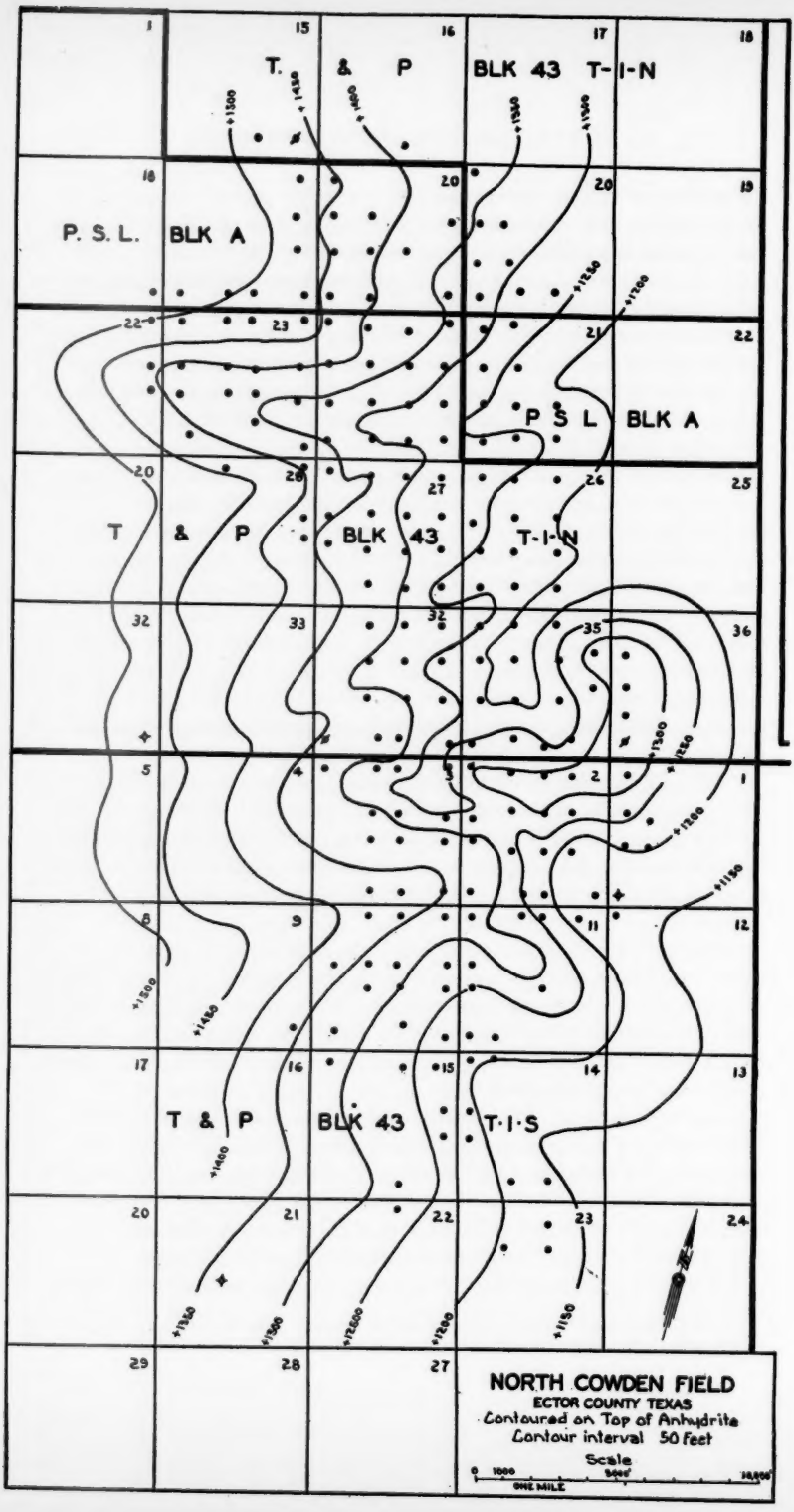

T. & P BLK 43 T-1-N
P. S. L. BLK A
P S L BLK A
T & P BLK 43 T-1-N
T & P BLK 43 T-1-S
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
Contoured on Top of Anhydrite
Contour interval 50 feet
Scale
ONE MILE

FIG. 4.—Fifty-foot contours on top of Rustler formation ("Top anhydrite").

Salado is a section of salt 835 feet thick, broken by beds of anhydrite and potash in the form of polyhalite. Some thin beds of red sand are found in the upper part of the formation. It is interesting to note that some of the anhydrite beds in the Salado can be correlated for hundreds of miles in the subsurface. As the easily dissolved salt drills much faster than anhydrite, these "breaks" are easily discernible in carefully recorded rotary drilling time.

The lowermost of these anhydrite beds, occurring from 150 to 200 feet above the base of the formation, is herein named the Cowden anhydrite member. This bed has long been called by this name and used as a marker by subsurface geologists in the Permian basin, and the writers take this opportunity to define it. The type locality well, the discovery well of the North Cowden field, Southern Crude Oil Purchasing Company's J. M. Cowden No. 1, is located 2,310 feet from the north and 330 feet from the west lines of Sec. 26, Blk. 43, T. 1 N., T. & P., Ector County, Texas. It was completed in September, 1930, with an initial production of 777 barrels of oil per day, at the total depth 4,244 feet. The ground elevation at the well is 3,050 feet.

The cuttings of the type Cowden anhydrite are available for inspection in the files of several major oil companies in Midland, Texas. A description of the critical samples follows.

Depth in Feet

2,580–2,590 100% salt; trace of polyhalite
Top of Cowden anhydrite at 2,590 feet
–2,600 85% white crystalline porous anhydrite; 15% buff to brown slightly dolomitic anhydrite
–2,610 25% white and gray anhydrite; 75% salt, trace of fine red sand
–2,625 30% white and gray anhydrite; 70% salt
–2,640 trace of gray anhydrite; 100% salt
Base of Cowden anhydrite chosen at 2,605 feet

Thus the thickness of the type Cowden anhydrite is 15 feet. The thickness is considerably different in other localities; in some areas the member has a thickness of 50 feet, and in others only 10 feet. The composition of the bed is also variable in that in some places it is dolomitic. In the type locality well the Cowden anhydrite member is mainly white crystalline anhydrite, whereas in Gaines County, 70 miles north, the bed is composed of brown, earthy, dolomitic anhydrite. In southern Upton and in Pecos counties the member is also considerably dolomitic. In general, it may be stated that the bed is encountered from 150 to 200 feet above the base of the Salado formation in all wells drilled on the Central Basin platform and in the Midland basin.

The section from the base of the Cowden anhydrite member to the base of the Salado formation consists of salt with, in some wells, thin beds of polyhalite.

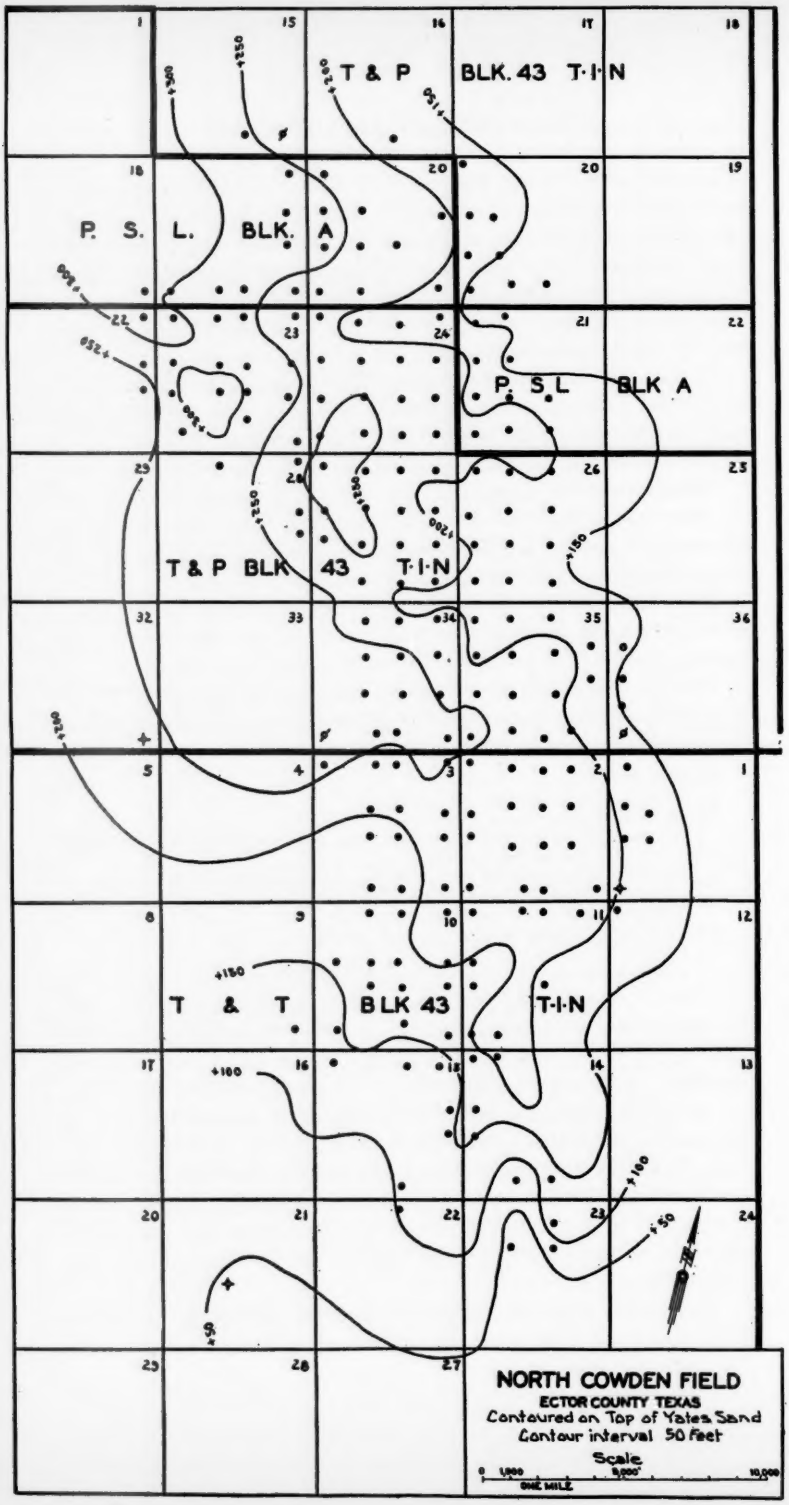

T & P BLK. 43 T-1-N
P. S. L. BLK. A
P. S. L. BLK A
T & P BLK 43 T-1-N
T & T BLK 43 T-1-N
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
Contoured on Top of Yates Sand
Contour interval 50 feet
Scale
ONE MILE

FIG. 5.—Structure of "Top Yates."

WHITEHORSE GROUP

The Whitehorse group consists of five formations named, in descending order, the Tansill formation, the Yates sand, the Seven Rivers formation, the Queen sand, and the Grayburg formation.

Tansill formation.[5]—Beneath the Salado salt occurs 75–125 feet of anhydrite, red shale and sand, and in places a few thin salt beds. The order of these beds in the formation is not constant, and in some wells in the field the Tansill consists almost entirely of anhydrite. The sand, where present, is almost identical with the subjacent Yates sand except for the lack of frosted quartz grains. A little red shale is ordinarily found at or near the top of the formation. On the section the Tansill extends from 2,750 to 2,850 feet.

Yates sand.—The Yates sand in the North Cowden field consists of about 200 feet of fine red sand broken with beds of anhydrite, here and there salt stringers, and varying quantities of red shale. The sand almost invariably contains numerous relatively large, rounded, frosted grains—a characteristic which makes the formation a most important marker in rotary wells, as it is ordinarily possible to detect the frosted quartz grains by careful microscopic examination of the cuttings. The structure of the field, contoured on the top of the Yates sand, is seen in Figure 5. Although local irreguiarities are present, the structure is easily recognized.

No showing of oil or gas is encountered in the Yates sand in the North Cowden field, although in some areas on the Central Basin platform it is an important oil reservoir.

Seven Rivers formation.—Immediately below the Yates sand is a second predominantly evaporite section consisting of alternating beds of anhydrite and salt and some thin beds of red shale and sand. On the section it is represented as being 530 feet thick, extending from 3,085 to 3,615 feet. The sands of the Seven Rivers formation are lithologically similar to the Yates sand above and in places contain frosted sand grains. Although some thin polyhalite beds are encountered in this second evaporite section, they are erratic and unimportant as markers.

Queen sand.—Immediately below the Seven Rivers evaporite beds, between the depths of 3,615 and 3,875 feet, the discovery well penetrated a section composed predominantly of anhydrite with a few thin brown limestone stringers. Little salt is present in this section in the North Cowden field. A friable red sand commonly occurs at the top of the formation and in this saline water is encountered. The discovery well logged one bailer of water per hour from this sand. Limestone beds in the Queen sand are for the most part erratic stringers,

[5] Ronald K. DeFord and E. Russell Lloyd, "West Texas-New Mexico Symposium. Part I. Editorial Introduction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 9 and Fig. 2.

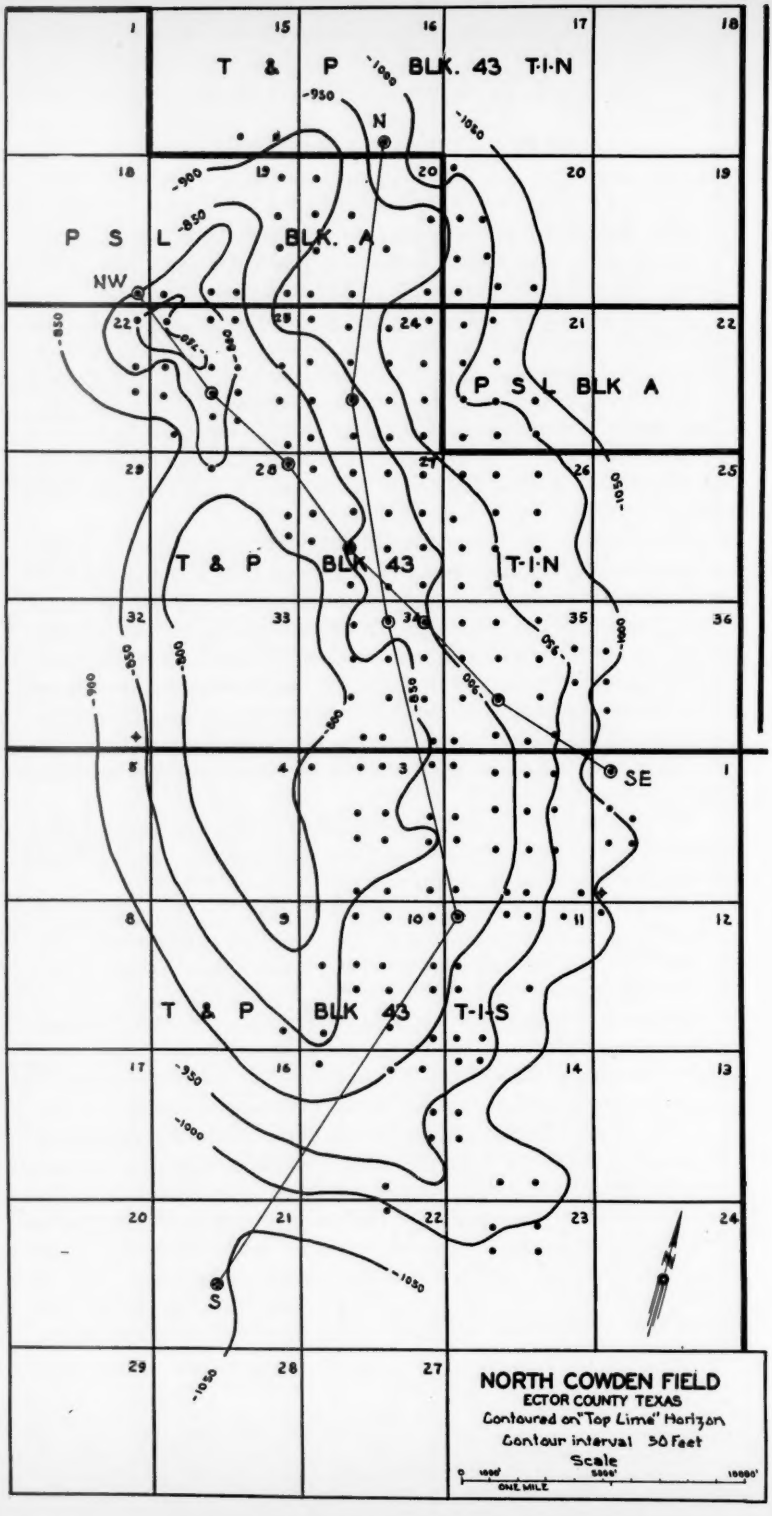


FIG. 6.—Structure of "Top lime" (top of Grayburg formation). NW–SE and N–S, lines of cross sections shown in Figures 8 and 9.

but one, occurring about 150 feet above the base of the formation, has been encountered by every well in the field. This is a brown to gray dolomite 10–25 feet in thickness, and is an excellent subsurface marker. In structurally high wells other limestone beds may be encountered between this marker and the base of the formation, but they appear to be of more limited extent. In the discovery well the section from the base of this limestone to the base of the formation is composed predominantly of anhydrite broken by a few thin sand and shale beds.

Grayburg formation.—The thickness of the Grayburg formation of the Whitehorse group, from which the North Cowden oil is produced is yet to be determined. Several wells have probably penetrated the entire section and entered the underlying San Andres limestone, but insufficient information is at present available to determine the Grayburg-San Andres contact.

Producing beds.—All production of gas and oil in the North Cowden field is from the Grayburg formation of the Whitehorse group. There are four sands in the first 400 feet of the Grayburg which have been taken as criteria for the designation of the four producing members or "pays." The third "pay" is more uniformly consistent in thickness throughout the field, and it is likewise the most important economically. (The field has been divided into three "salients" based on the number of "pays" penetrated as shown in Figure 7.)

The interval from the top of the limestone to the first "pay" ranges in thickness from 30 to 55 feet. Throughout the field there are local variations in this section, but the interval is composed in general of white and buff, dense to finely crystalline, oölitic and anhydritic magnesian limestone interbedded with fine-grained angular red and gray calcareous cemented sands and thin laminations of green and maroon bentonitic shales.

First "pay".—The first "pay" is ordinarily 50–70 feet thick. This stratum is present throughout the field but the thickness (3–15 feet) and lithologic character of the included sand varies considerably. It is generally very fine-grained angular clear quartz sand showing varying degrees of calcareous cementation and is associated with light gray and brown, sandy and anhydritic, dense to finely crystalline magnesian limestone. Near the base of the "pay" there is in most places a marked change in the color of the magnesian limestone from the light to darker shades. In some of the larger gas wells on the east side of the field, prolific oölitic beds have been found near the base of the "pay." (Only 15 per cent of the wells in the field obtain commercial quantities of oil from this "pay.")

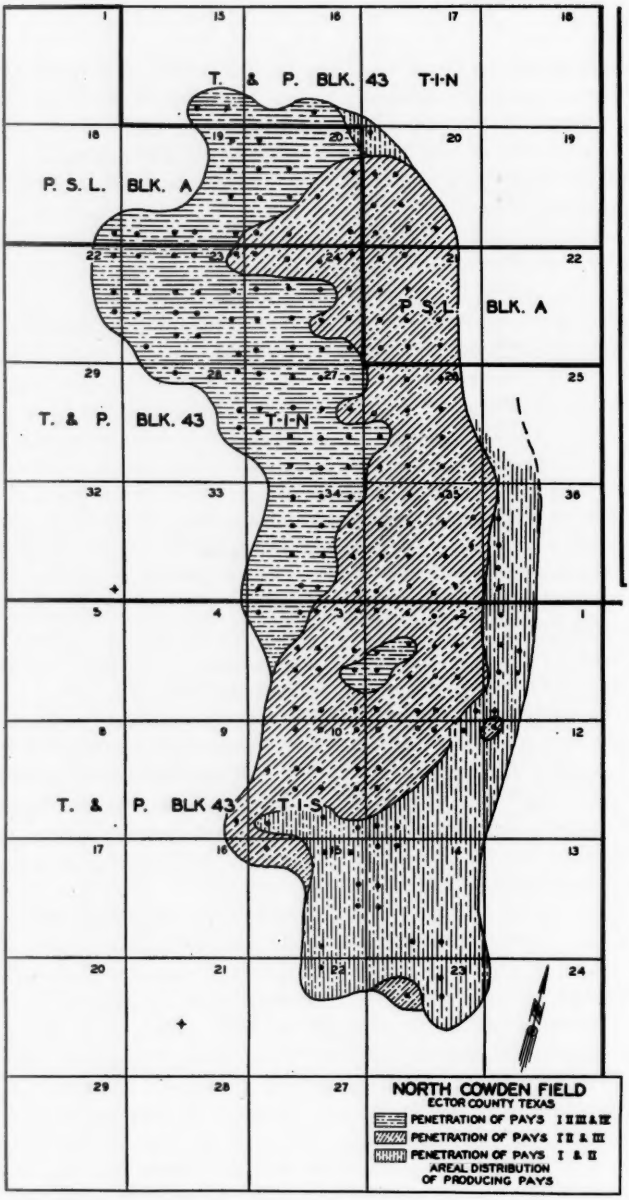

T. & P. BLK. 43 T-1-N
P. S. L. BLK. A
P. S. L. BLK. A
T. & P. BLK. 43 T-1-N
T. & P. BLK 43 T-1-S
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
PENETRATION OF PAYS I II III & IV
PENETRATION OF PAYS I II & III
PENETRATION OF PAYS I & II
AREAL DISTRIBUTION
OF PRODUCING PAYS

FIG. 7.—Areal distribution of "pays" in North Cowden field.

Between the first and second "pay" is an interval 40–60 feet thick of predominantly light gray, anhydritic, and slightly sandy magnesian limestone. In general, the last 10 feet of this section is light buff, very oölitic, magnesian limestone.

Second "pay."—The top of the second "pay" in many places is difficult to correlate inasmuch as the sand grades into sandy magnesian limestone around the outer edges of the field. Throughout the central part of the field considerable green bentonitic shale is associated with the sand in the upper 30 feet of the "pay." The sand is in thin streaks between alternate layers of bentonite and light gray and brown, fine to coarsely crystalline, sandy, and anhydritic magnesian limestone. Approximately 55 feet of section is included in the second "pay," and every oil well in the field, except one, is producing oil or gas or both from this interval. The actual sand thickness varies from 2 to 20 feet.

Just below the base of the second "pay" is an interval of approximately 30 feet consisting of buff to dark brown, slightly sandy and anhydritic, finely crystalline magnesian limestone which is very oölitic in the south half of the field. In many wells having a limestone datum of −950 or lower, this section is porous and yields considerable oil. This is especially true along the east flank of the structure. The remaining 15 feet between the second and third "pays" is composed of light gray and buff, dense to finely crystalline, very oölitic magnesian limestone. This bed serves as a cap rock to the third "pay" in the central parts of the field.

Third "pay."—The third "pay" is predominantly sand; however, the thickness of the sand ranges from 10 to 40 feet. There is a wide lithologic variation in the sand. Solubility analyses have been made of sands from wells in every part of the field; in general, the sands on the west side show an average of 60 per cent calcareous cement, whereas the wells in the central and eastern parts show an average of 15 per cent calcareous cement. An average of 30 feet of section is generally assigned to the third "pay." When limestone is present, it commonly is dark brown, finely crystalline, oölitic magnesian limestone. The sand is composed of fine-grained angular quartz grains cemented with secondary anhydrite crystals. Approximately seventy wells in the central and east-central parts of the field have well developed sand beds in this "pay."

The average 30-foot interval between the base of the third and top of the fourth "pays" varies considerably from east to west. In general there is a decided gradation from light gray and buff, finely crystalline, sandy magnesian limestone to alternating thin-bedded, highly calcareous, gray, fine-grained sands and sandy gray and buff magnesian limestone. As regards the degree of saturation, there is no demarcation

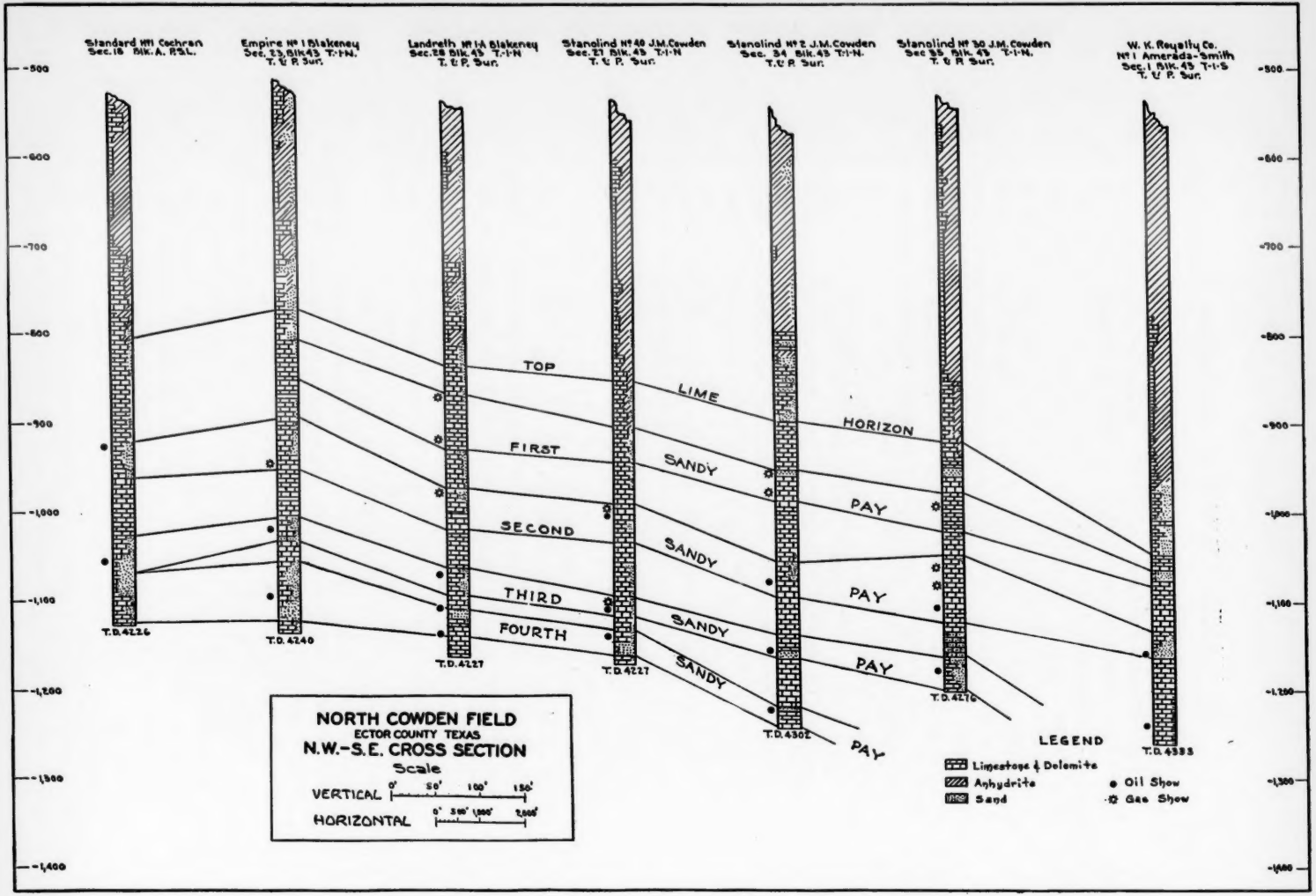


FIG. 8.—Northwest-southeast cross section of producing beds in North Cowden field.

between the third and fourth "pays" in the west halves of Secs. 34, 27, and 24, and all of Sec. 23. Blk. 43, T. 1 N., T. & P.

Fourth "pay."—The fourth "pay" ranges in thickness from 10 to 40 feet; the maximum thickness is present in the aforementioned sections and in the ring of wells surrounding Section 23. Approximately sixty wells in the field are producing from the fourth "pay." The lithologic character of the sand in the fourth "pay" is similar to that in the third "pay"; in general, however, the degree of cementation is somewhat higher. Finely crystalline, brown and light gray, anhydritic and sandy magnesian limestones are associated with the sand. The basal part of the "pay" is ordinarily light gray, very finely anhydritic, magnesian limestone.

Four important conclusions concerning the pay section are derived from a study of solubility tests made of key wells throughout the field. First, there is considerably more secondary anhydrite present in wells on the west side of the field than on the east side. Second, in general, there is more secondary anhydrite in the first "pay" than in the second "pay." Third, some wells whose pay sections show considerable anhydrite make excellent producers; this can be explained by assuming that the original pore space was so well developed that the deposition of secondary anhydrite during post-Grayburg time failed to close the pore space. Fourth, the amount of secondary anhydrite, present in the first and second "pays" combined, ranges from 4.8 to 22.3 per cent.

STRUCTURAL HISTORY

The formation of the North Cowden structure appears to have been progressive throughout the Permian period. That the region was undergoing uplift during the deposition of the producing section (Grayburg) is suggested by Figure 10 which indicates the approximate attitude of the base of the third "pay" at the time of the horizontal deposition of the first. Although several channels cut into the structure from both west and east, the general alignment of areas of thin deposition indicates that folding was in progress in the time interval represented, and that the axis of this old structure was slightly east of the axis of the present limestone "high."

From the time of the deposition of the producing beds to the present, the axis of the North Cowden fold has shifted considerably. In the epoch represented by the sedimentation from the end of Grayburg time to the end of Yates time, the axis was about $\frac{1}{4}$ mile east of its present position, and in Salado time about $1\frac{1}{4}$ miles east. The orientation of the axis has remained approximately the same from Grayburg to the present.

FIG. 8.—Northwest-southeast cross section of producing beds in North Cowden field.

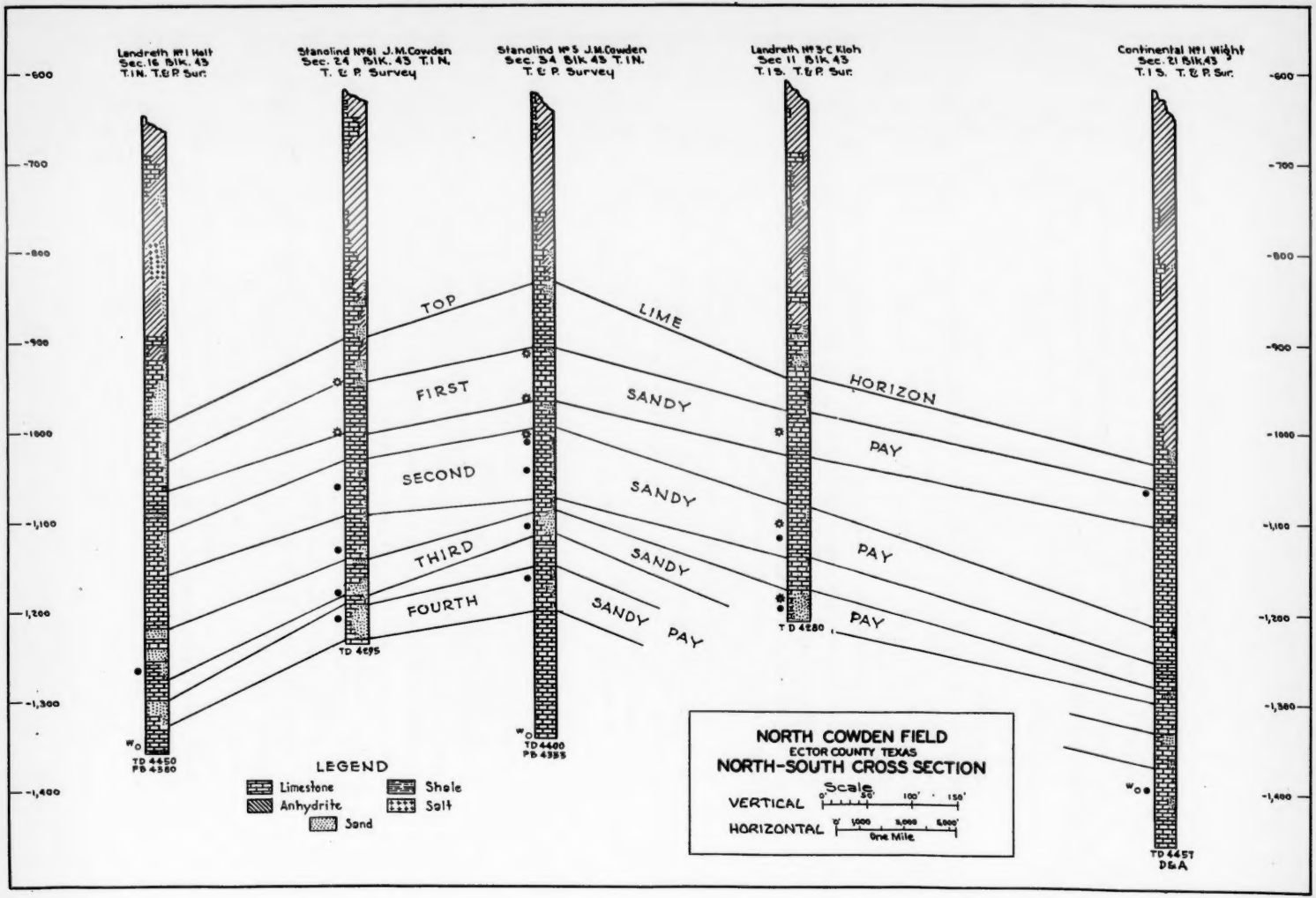


FIG. 9.—North-south cross section of producing beds in North Cowden field.

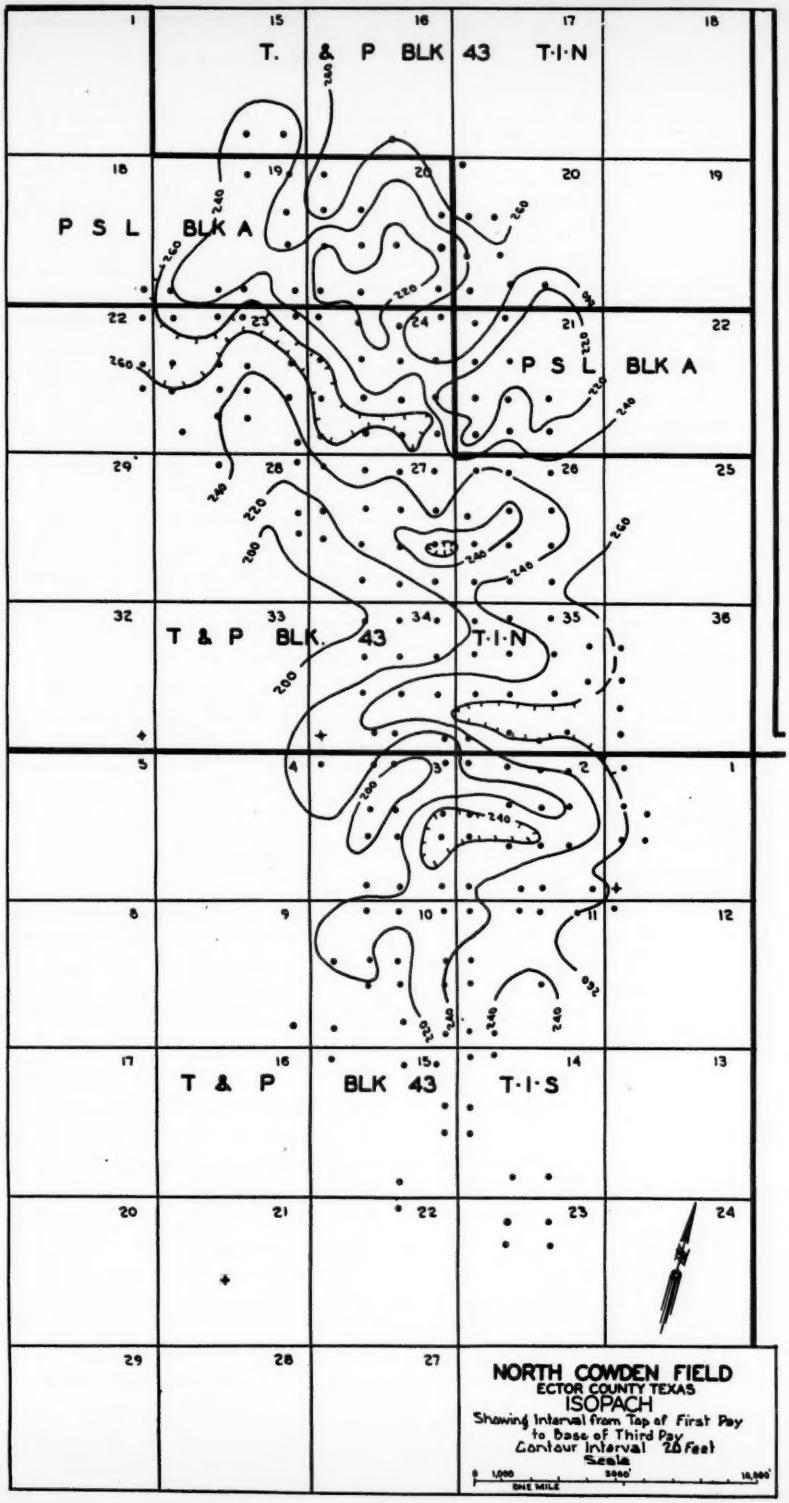

T. & P BLK 43 T·1·N
P S L BLK A
P S L BLK A
T & P BLK. 43 T·1·N
T & P BLK 43 T·1·S
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
ISOPACH
Showing Interval from Top of First Pay to Base of Third Pay
Contour Interval 20 Feet
Scale
ONE MILE

FIG. 10.—Thickness of interval between top of first "pay" and base of third "pay."

FIG. 9.—North-south cross section of producing beds in North Cowden field.

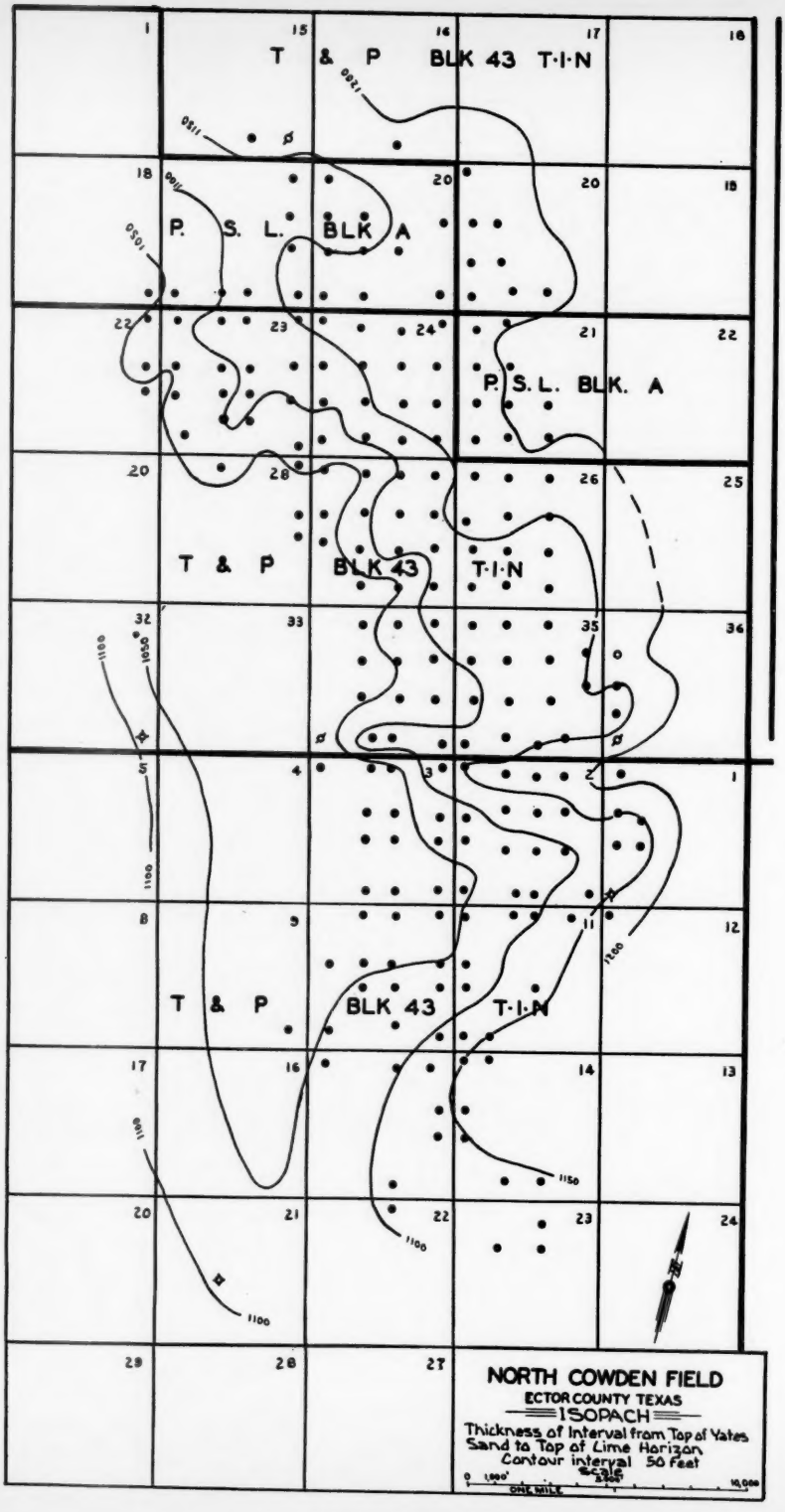


FIG. 11.—Thickness of interval between top of Yates and "Top lime."

Uplift appears to have occurred somewhat erratically. On the east flank and southern extremity of the structure the most intense folding was confined to Whitehorse and Salado time, with a relatively slight amount of post-Rustler movement indicated. On the west flank, however, about one-third of the movement since limestone deposition seems to have occurred in Rustler and post-Rustler time. Movement since the deposition of the Rustler formation, including the folding previously mentioned, tilted the area east, or basinward.

Pre-Yates folding.—The thickness of the interval between the "Top lime" horizon and the top of the Yates sand is mapped in Figure 11. It approximately represents the position of the "Top lime" horizon when the Yates sand was being deposited, and it shows that the North Cowden structure was almost as well defined in Yates time as at the present. Inaccurate choice of "Top lime" and Yates datum points probably accounts for some of the local irregularities. The axis of this Whitehorse folding was east of the axis of the present structure, and the dip on the east flank was not as pronounced as it is at present. Just how much of this folding occurred immediately after limestone deposition is not known.

Post-Yates folding.—The interval between the top of the Yates sand and the top of the Rustler anhydrite is mapped in Figure 12. These contours represent the approximate attitude of the Yates formation during the supposedly horizontal deposition of the Rustler anhydrite. This map does not present as accurate a picture as is portrayed in Figure 11 because of the difficulty in picking the actual top of the anhydrite in many well records. Cuttings from rotary wells are ordinarily not available this high in the section, and choice of many tops had to be made from drilling time. Local irregularities are almost undoubtedly due to this difficulty. However, the North Cowden structure is definitely reflected by this map although the axis is offset even more to the east, as compared with the present structure, than was the axis in pre-Yates time. Dip on the east flank of the fold was somewhat diminished, and west dip increased, by this eastward shifting of the axis.

The one well that is definitely down the west flank of the structure, Gilpin *et al.* Blakeney No. 1, shows little evidence of thickening section (hence little evidence of subsidence) in pre-Yates time. However, the section from the Yates sand to the top of the Rustler anhydrite shows an increase of thickness amounting to about 200 feet as compared with wells due east on the crest of the structure. Most of this thickening occurs in the Rustler formation, so it may be inferred that subsidence on the west flank of the fold was in progress during Rustler time, or that post-Rustler solution or erosion took place on the crest of the structure.

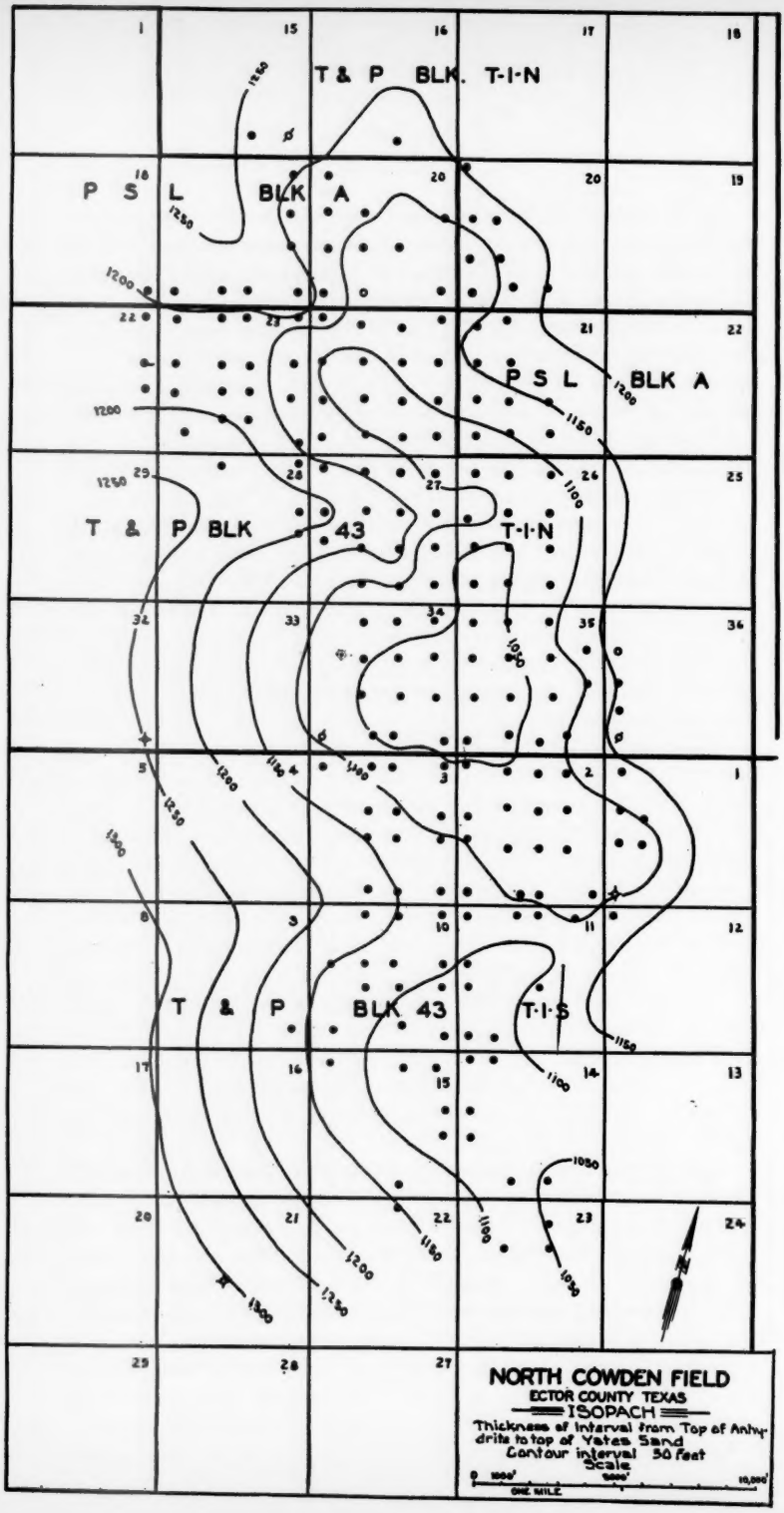


FIG. 12.—Thickness of interval between top of Rustler and top of Yates formations.

Post-Rustler movement.—Figure 4, contoured on the top of the Rustler anhydrite, roughly indicates the folding since the deposition of the Rustler formation. The accuracy of the map is probably affected to a marked degree by lack of exact data in records of rotary wells, as previously remarked. Moreover, study of cable-tool wells reveals the fact that the attitude of the top of the Rustler is erratically affected by the variations in thickness of the formation. The "Top anhydrite" map strongly resembles a topographic picture, and it is possible that shortly after deposition the Rustler beds were eroded and rapidly submerged so that the superjacent red clastics of the Dewey Lake formation were deposited on a moderately rugged surface. Or slumping, consequent to the solution of salt beds, may have developed a karst topography for the area in late Rustler or Dewey Lake time. The closure contoured on the "Top anhydrite" in the east-central part of the field may be the result of such erosion or slumping, as may be also the channel or trough cutting across the north part of the field. In general, it may be observed that post-Rustler folding consisted more of eastward tilting than of centralized uplift in the North Cowden area. All that remains of the west dip indicated by the maps of previous epochs of folding is a more gradual east dip on the top of the Rustler on the west side of the field. The degree of dip increases from west to east across the field.

Unfortunately, the attitude of the Triassic formations in the North Cowden area is not accurately known on account of the difficulty of correlating rotary records in this "redbed section," but it is probable that the structure is indicated in the attitude of the base of the Santa Rosa sandstone.

RESERVOIR CONDITIONS

RESERVOIR PRESSURES

The study of bottom-hole pressures began in July, 1933, approximately 3 years after the discovery well was brought in. On the first survey, only two wells, $\frac{3}{4}$ mile apart, were tested; the average pressure corrected to −1,000 feet was 1,653 pounds per square inch. Thereafter, readings were made every 90 days, and the records show a decided tendency toward pressure fluctuation, with recorded variations of as high as 167 pounds in a 90-day period. This fluctuation in static reservoir pressures was due, in part, to field adjustment as a result of additional drilling activities, together with large per-well allowables.

The original reservoir pressure, corrected to 1,000 feet below sea-level, is thought to have been 1,750 pounds per square inch. The highest recorded pressure was 1,730 pounds per square inch.

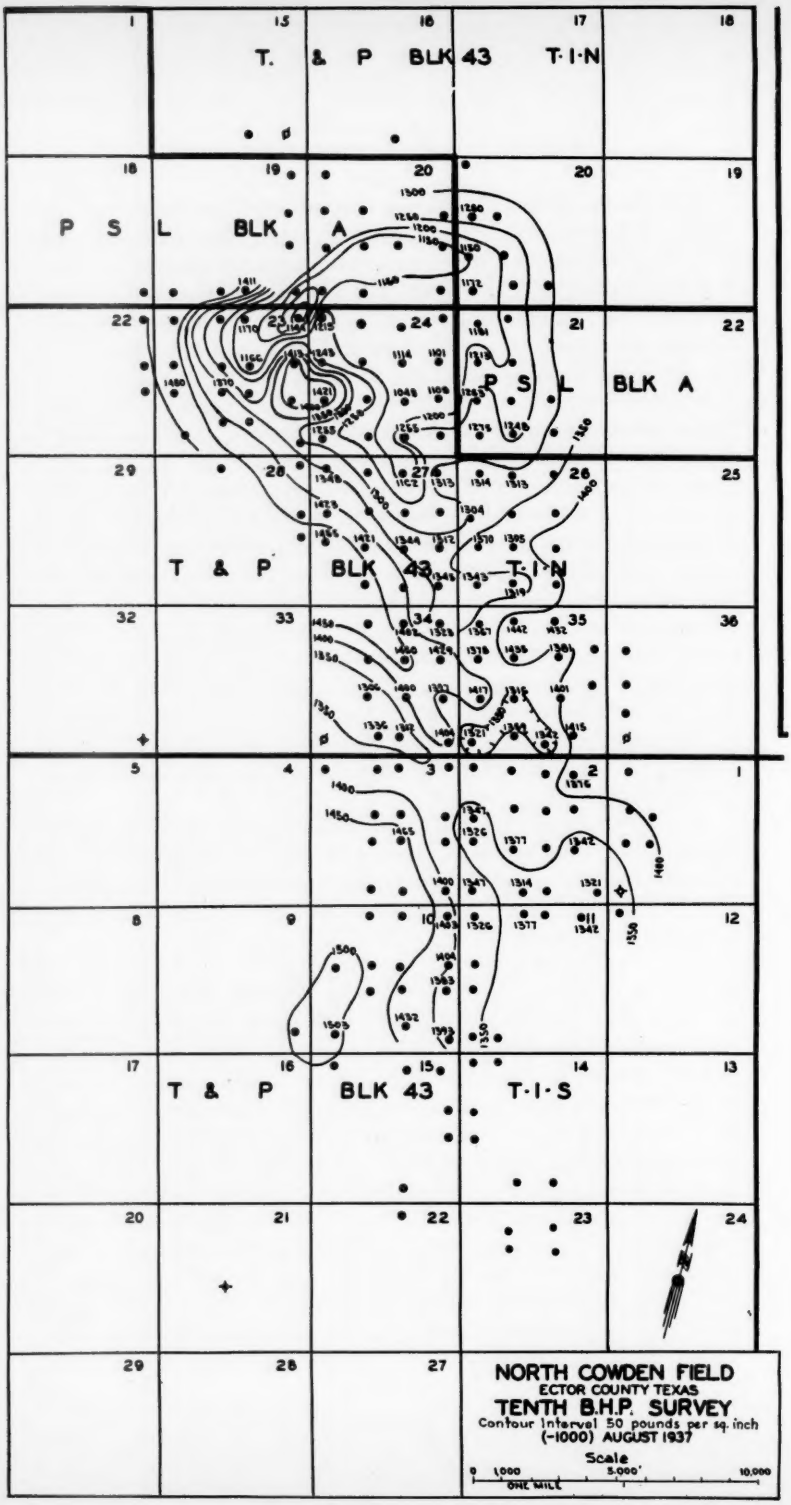

T. & P BLK 43 T-1-N
P S L BLK A
T & P BLK 43 T-1-N
T & P BLK 43 T-1-S
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
TENTH B.H.P. SURVEY
Contour Interval 50 pounds per sq. inch
(-1000) AUGUST 1937
Scale
0 1,000 5,000 10,000
ONE MILE

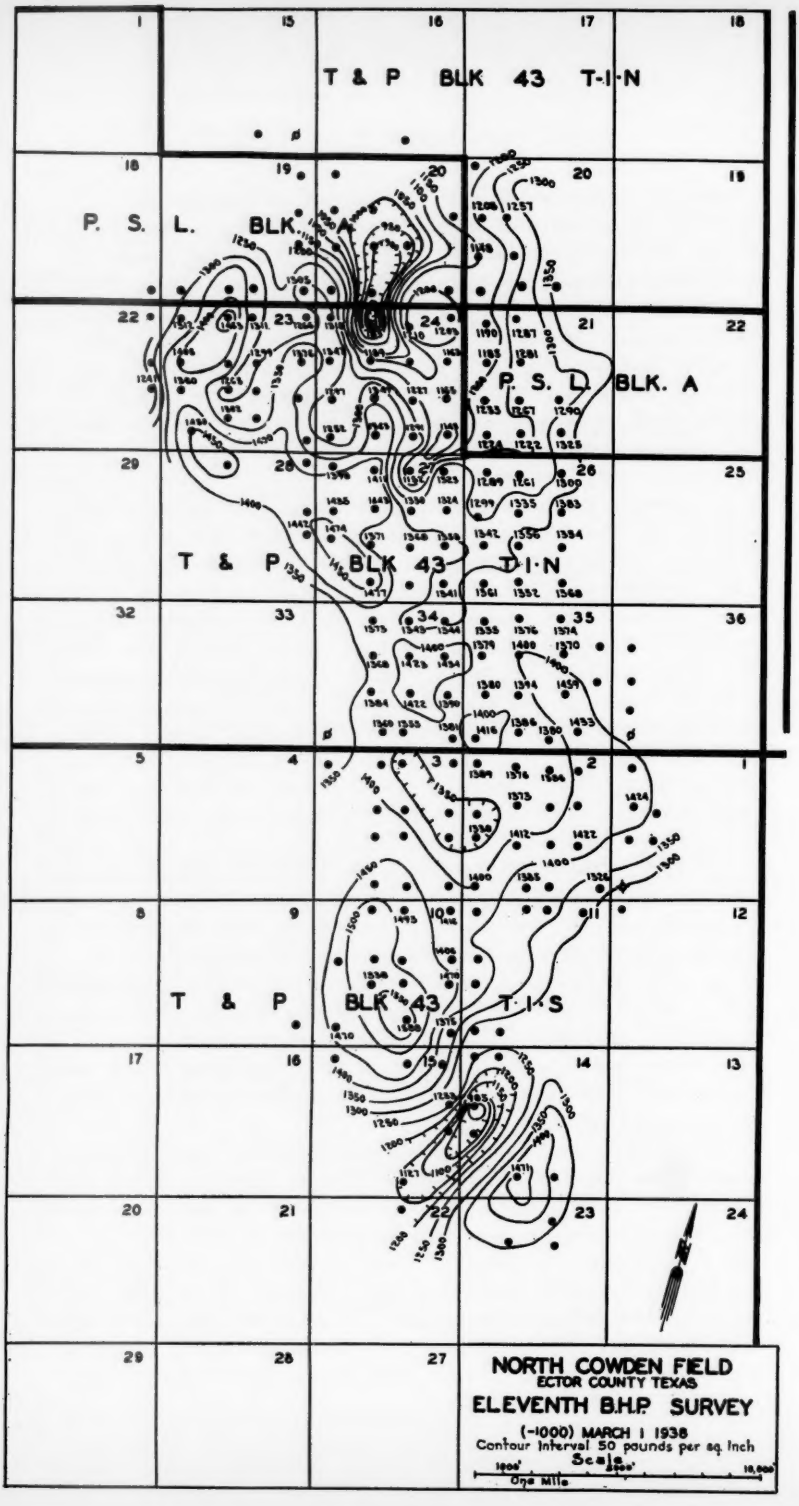
FIG. 13.—Bottom-hole pressures, August, 1937. Contour interval, 50 pounds per square inch.

Development of the field spread in all directions from the discovery well during the period of intensive drilling that began in the latter part of 1935. The first general survey of the reservoir pressure revealed a low-pressure area adjacent to the discovery well. This survey of 34 key wells in the central and southern part of the field was made on January 1, 1936, and indicated the average pressure to be 1,519.5 pounds per square inch, or a decrease of 230.5 pounds from the arbitrarily established original pressure. (All pressures were corrected to a datum of −1,000 feet.) At the time of this survey, there were only 52 producing wells, and the total cumulative production was approximately 1,675,000 barrels.

On January 1, 1937, the second general pressure survey of the field was completed and showed the area of lowest pressure to be centered in the north end of the Stanolind Oil and Gas Company's J. M. Cowden lease. The lowest recorded pressure obtained was 1,014 pounds per square inch in J. M. Cowden No. 37. The higher pressures recorded were, in general, along the west side of the field near the crest of the structure. This might logically be explained by a repressuring effect from the undeveloped gas cap. The bombs were run in 52 key wells in this survey; they indicated the average pressure to be 1,407 pounds per square inch, a decrease of 112.5 pounds from the previous survey. The cumulative production of the field from 107 completed wells, ending on January 1, 1937, was 3,947,083 barrels, or an increase over the last survey of 2,272,083.

A survey of the north three-quarters of the field, completed on August 1, 1937, indicated the lowest pressure area to be in Sec. 24, Blk. 43, T. 1 N., in the north-central part of the field. Another low-pressure area was developed in the extreme northeast part of Section 23, as shown in Figure 13. Approximately 85 wells were used in this survey; they indicated a field-average pressure of 1,338 pounds per square inch. On August 1, 1937, there were 142 completed wells with a cumulative production of 5,401,970 barrels. The decrease in average pressure for the field was 69 pounds and the increase in the number of producing wells was 35.

The next field-wide survey, completed on March 1, 1938, definitely confirmed the low-pressure area depicted in the previous survey. In general, the higher pressures were recorded along the west side of the field. A definitely low-pressure area developed in the south part of the field in Secs. 14 and 15, Blk. 43, T. 1 S., as shown in Figure 14. Approximately 115 key wells, in practically every part of the field, were employed; they indicated the average pressure to be 1,333 pounds per square inch, or a decrease of 5 pounds from the last survey. Cumulative production for the field up to March 1, 1938, was 6,987,892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P. S. L. BLK. A
P. S. L. BLK. A
T & P BLK 43 T-1-N
T & P BLK 43 T-1-S
NORTH COWDEN FIELD
ECTOR COUNTY TEXAS
ELEVENTH B.H.P. SURVEY
(-1000) MARCH 1 1938
Contour Interval 50 pounds per sq. Inch
Scale
One Mile

FIG. 14.—Bottom-hole pressures, March 1, 1938. Contour interval, 50 pounds per square inch.

barrels, an increase of 1,585,922 barrels over the previous survey. A total of 187 producing wells was accredited to the field at this time.

The exceedingly slight change in the field's bottom-hole pressure averages for the last two surveys is due to widespread corrective work carried on by several operators, to curtailment in allowables, and to Sunday shut-downs.

A composite curve of production, development and bottom-hole pressures of the North Cowden field is shown in Figure 15.

GAS-OIL LEVELS

The base of the free gas in the North Cowden reservoir, in general, is between −980 and −1,020 feet. The contact between the gas and oil is in many wells interrupted by impervious limestone beds, and the variation in the level at which free gas is encountered may likewise be explained by varying depositional and structural factors.

The first and second "pays" contain gas in the North Cowden reservoir when they occur structurally high enough to be above the gas-oil contact.

In general, the wells in the field where "top-lime" datum points are below −950 do not have free gas.

OIL-WATER LEVELS

There is no definite oil-water contact in the North Cowden reservoir. Information regarding formation waters in the field is meager and confusing. Both sulphur and salt waters have been reported in the second "pay" at datum points ranging from −1,196 feet to −1,213 feet; in the third "pay," −1,134 feet to −1,201 feet; in the fourth "pay," −1,140 feet to −1,279 feet.

Three wells have encountered sulphur water below the producing section in the field. The Stanolind Oil and Gas Company's J. M. Cowden No. 5, which penetrated all four "pays" without encountering any formation water, was purposely deepened in search of water, which came in at 4,395 feet (−1,333 feet). The other two wells encountered water at −1,273 feet and −1,350 feet. The controversial conclusion is that the water encountered in these wells represents the bottom-hole water table, and that its irregularity may be satisfactorily explained by differential porosity in the limestone. All waters encountered in the pay sections are connate.

WATER ENCROACHMENT

Water encroachment in its broadest sense is the vertical migration of water to occupy the space voided by the withdrawal of oil and gas. The North Cowden reservoir with its four sandy "pays," separated in most places by impervious magnesian limestones, is not likely to

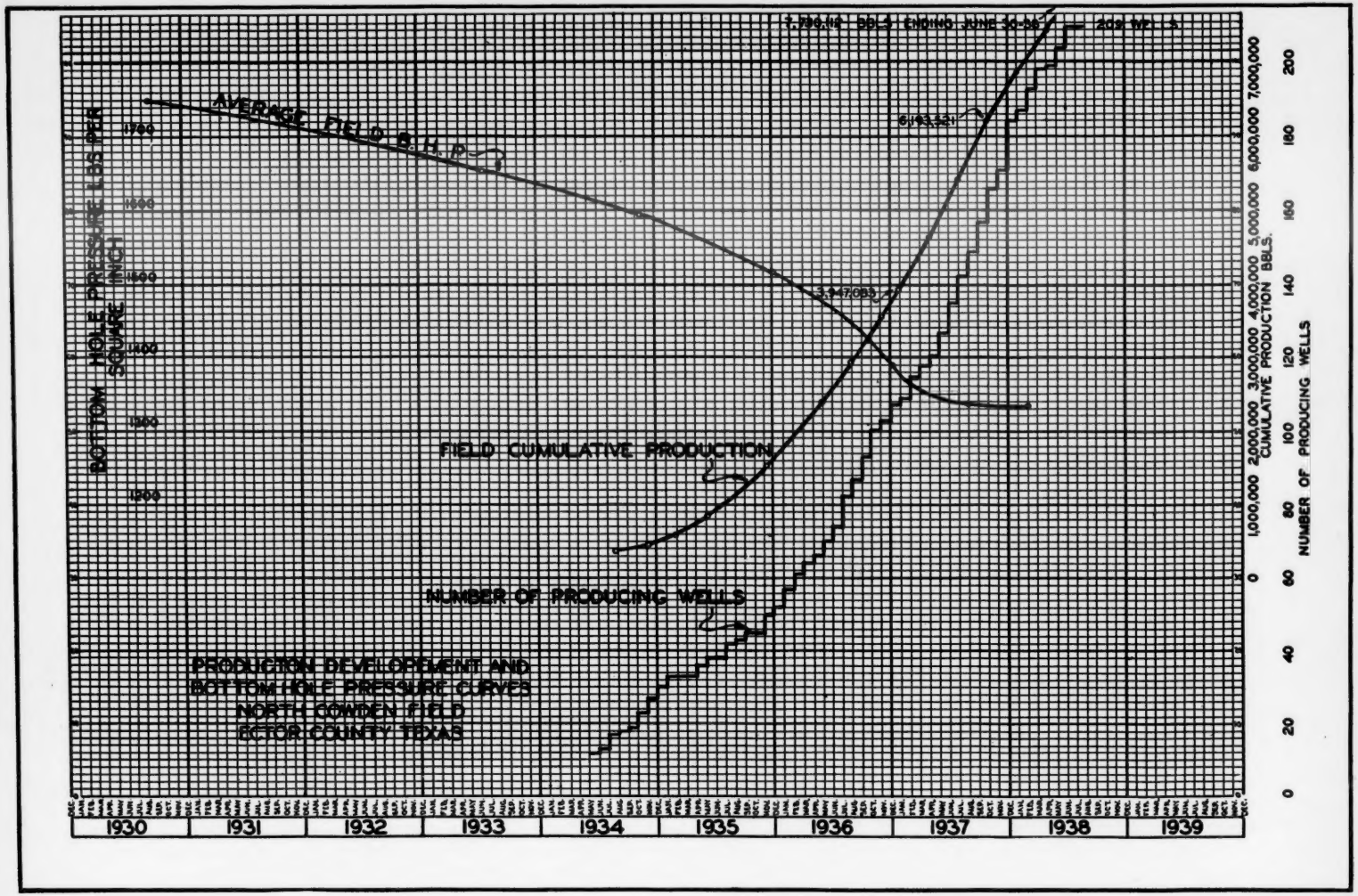

FIG. 15.—Composite development and production data

witness any active water encroachment from one "pay" to another. The extreme differential porosity in the pay sections between adjacent wells minimizes the danger of extensive water flooding.

Two areas in the field contain wells which have commenced making water since their completion. The first area contains five wells and embraces parts of Secs. 9, 15, 14, and 23, Blk. 43, T. 1 S., in the extreme south part of the field. The volume of water produced by these wells varies from ½ to 3 barrels daily. This is not evidence of active encroachment for the volume of water is not materially increasing.

The second area is the W. ½ of Sec. 34, Blk. 43, T. 1 N., and the NW. ¼ of Sec. 3, Blk. 43, T. 1 S. Five wells are producing 1–6 barrels of salt water daily from the fourth "pay." When the water was discovered in four of these wells, the volume was considerably higher and this water was later exhausted in several wells.

Either salt or sulphur water was found in 22 wells at the time they were drilled; in eleven of these the water was successfully plugged off before completion.

ANALYSIS OF TYPICAL SALT WATER FROM THE NORTH COWDEN FIELD

Stanolind Oil and Gas Company's J. M. Cowden No. 7, SW. ¼ Sec. 34, Blk. 43, T. 1 N., T. & P.

Sample from separator, collected February 9, 1938

	Per Cent by Analysis	*Parts per Million*	*Reacting Values Per Cent*
Na	33.84	38,794	42.95
Ca	3.73	4,279	5.43
Mg	0.67	773	1.62
SO_4	2.53	2,896	1.53
Cl	58.46	67,019	48.10
HCO_3	0.77	878	0.37
H_2S	Present		
Total	100.00	114,639	100.00
Total solids by evaporation		98,960	

Specific gravity, 1.0752

GAS CAP

The areal extent of the proven gas cap is outlined in Figure 16. Approximately 118 wells representing 4,720 producing acres are included in the known gas cap. There are probably 1,200 additional acres that should be included, but as yet they are undeveloped.

There is no accurate survey possible of the aggregate volume of gas originally present in the first and second "pays," which constitute the gas reservoir. The recorded initial productions of gas from wells drilled within the limits of the cap range from slightly less than a million to 15 million cubic feet daily. Wide variation in thickness and porosity of the gas-bearing "pays," coupled with inaccurate or missing samples of the section, prevent accurate calculation of reserves.

FIG. 15.—Composite development and production data.

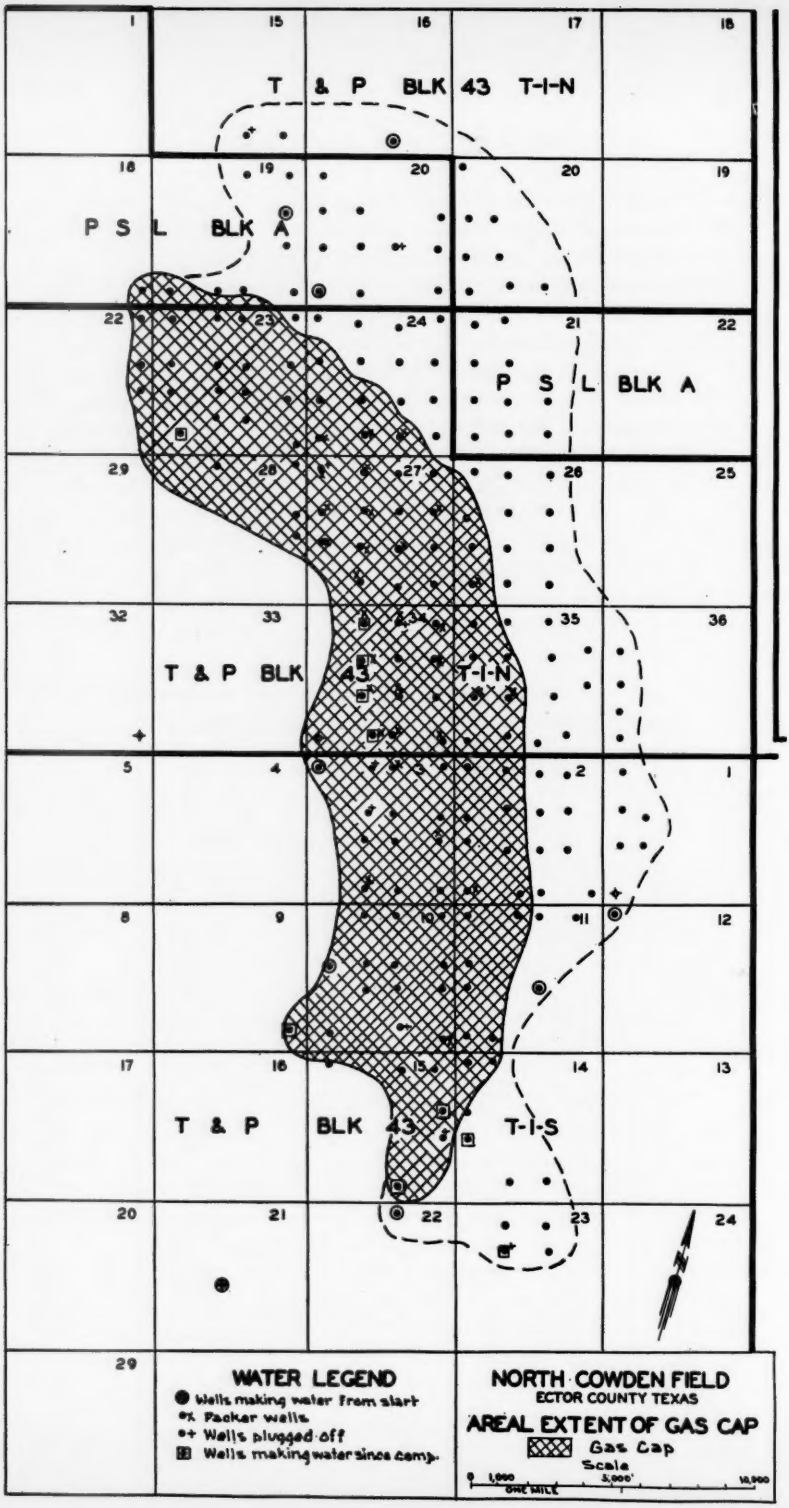

FIG. 16.—Gas cap and water data, September 1, 1938.

The commercial importance of the gas reserve as fuel is negligible as compared with its value as stored energy to be used in producing oil after the field proper will no longer flow naturally. Unfortunately the gas cap has not been preserved intact, and millions of feet of gas have been wasted.

ANALYSIS OF TYPICAL GAS SAMPLE FROM THE NORTH COWDEN FIELD

Stanolind Oil and Gas Company's J. M. Cowden No. 22, Sec. 27, Blk. 43, T. 1 N., T. & P.

	Per Cent
Carbon dioxide	None
Oxygen	None
Methane	69.3
Ethane	27.3
Nitrogen	3.4

Hydrogen sulphide, 4.4 grains per 100 cubic feet

Calculated heat value at 30 inches and 60°F., 1,178 British thermal units per cubic foot.
Calculated heat value at 14.4 pounds plus 8 ounces and 60°F., 1,192 British thermal units per cubic foot.

GAS-OIL RATIOS

All evidence available from field operations and sample determinations indicates that the North Cowden is primarily a gas-drive field. The importance of water encroachment as a drive factor in the field must be ascertained later.

At the beginning of development, few operators realized the importance of preserving the gas. As a result many wells were shot too high in the section to allow for packer installation to seal off the excess gas. One operator has successfully lowered the gas-oil ratio in 25 wells by installing formation packers. Doubtless, most of these installations would have been unsuccessful if there had not been a considerable interval between the gas contact and the shot hole.

The Railroad Commission requested periodic gas-oil reports from all operators during 1936–1938 and penalties were assessed against wells with excessive ratios. In September, 1938, the limit was 3,500 cubic feet per barrel.

Some bottom-hole oil samples have been tested to determine the gas-oil solution ratio, but the results of the tests have been rather divergent, doubtless because reservoir conditions are different in different wells. The results from these tests do show, however, that the wells in the field are producing far more gas than that dissolved in the oil and that a further curtailment of the permissible gas-oil ratio is necessary for the preservation of the field's gas energy.

DRILLING METHODS AND PRACTICES

Of the 212 wells drilled prior to July 1, 1938, in the North Cowden field, 67 were drilled with rotary tools from the surface to the total

depth; 114 were drilled to the oil-string casing point with rotary tools and completed with cable-tool units; and 31 were drilled with cable tools. The majority of the rotary wells were tested for deviation from the vertical every 400 feet; and the common means of measurement was the Syfo or acid-bottle methods. It has been customary, also, in making contracts, to specify that no more than a maximum of 5° deviation from the vertical would be permitted. As a result of strict adherence to this precautionary measure, most of the wells in North Cowden field are comparatively straight holes.

In 1932–1933 the average time for drilling in and completing a producer with rotary-cable tool combination rigs was 56 days. During this same period the wells drilled from the surface to the total depth with cable tools required 90 days or more. In 1937, when 76 wells were added to the field, the average time required for drilling in and completion of rotary wells was 42 days, combination 50 days, and cable tools 80 days.

The accepted casing program for rotary and combination wells includes a surface string of $10\frac{3}{4}$-inch, outside diameter, casing at approximately 200 feet. The length of the string depends on the depth at which the redbeds are encountered. This casing is usually $40\frac{1}{8}$-pound seamless pipe set with enough cement to insure "returns" to the surface. Structural position of the wells determines to a large extent the amount of 7-inch, outside diameter, casing to be set. The average depth for the field is 4,000 feet; the amount of cement used varies from 85 to 250 sacks. Operators drilling with cable tools find it necessary to run either four or five strings of casing. Landreth's Blakeney No. 1-A, Sec. 28, Blk. 43, T. 1 N., a cable-tool well drilled near the apex of the structure, required 127 feet of 13-inch O.D., 1,416 feet of $10\frac{3}{4}$-inch O.D. (mudded), 2,895 feet of $8\frac{5}{8}$-inch O.D. (mudded), and 3,925 feet of 7-inch O.D. (cemented).

Practically all the rotary drilling is done with medium heavy-duty equipment using 94-foot or 122-foot dericks. An 11-inch hole is drilled using $6\frac{5}{8}$-inch O.D. drill pipe to the surface casing point; then the hole is reamed to $13\frac{3}{4}$ inches. The interval between the surface pipe and the oil-string casing point is drilled with 4-inch drill pipe cutting an $8\frac{1}{4}$-inch hole. Drag bits are very efficient through the soft redbed interval between 200 feet and 1,600 feet, and the remainder of the hole is drilled with rock bits. On a combination well, immediately after the 7-inch casing is run and cemented, the rotary tools are removed and either a cable-tool adaption or Cardwell unit installed. The time required for the installation of cable tools is from 4 to 10 days, whereas a Cardwell unit may be moved in and rigged up in less than a day.

Fuel and water are abundant, and on all wells except the earliest, natural gas has been used to furnish steam power. A single water well, drilled conveniently near each rotary location, generally supplies enough water to fire three 125-horsepower boilers. From 10 to 20 tons of imported mud are necessary to drill the surface hole. Natural mud is made in sufficient quantities from the formation below the surface casing to guarantee at least a 10-pound drilling fluid without the addition of any more mud. After the oil-string casing point is reached and before the casing is run, the circulating fluid is conditioned with either Jelox or Aquagel. Practically no serious attention has been given to the study of mud conditioning in the North Cowden field other than that necessary to obtain workable sample cuttings. There is no gas-producing bed above the first "pay," and most of the wells are cased above this "pay."

COMPLETION PRACTICES

Drilling in with oil.—Most of the operators drilling in with rotary tools circulate with live oil in order that the porous beds will not be flooded with water or sealed off with heavy mud.

Shooting.—Only 24 wells, or approximately 11 per cent of the field total, would be commercial producers without the use of nitroglycerine. In general, the second and third "pays" are heavily shot in order to establish satisfactory potentials; however, in many wells on the crest of the structure only the third and fourth "pays" are shot. The largest shells which can be conveniently and safely run are placed opposite the most lucrative "pays," and usually the poorly developed or barren sections are spaced with 3-inch shells. Most of the clean-out work in the North Cowden field was done with cable tools until Beckman's reverse-circulation method was introduced. With this method, oil is circulated down the casing and upward and out through the tubing to give it a high-carrying velocity.

Acidizing.—Up to September 1, 1938, ten wells have been treated with acid; six of these were shot and then acidized without a representative test between the two operations. The Stanolind Oil and Gas Company's J. M. Cowden No. 51, in the east-central part of the field, was treated with acid before drilling into the third "pay." Production from the first and second "pays" was increased from 1½ barrels an hour to 3 barrels an hour. In the extreme southern part of the field, where only the first two "pays" were penetrated, three wells were treated with an average of 3,000 gallons of acid. The resultant potentials were conformable with those of structurally equivalent adjacent wells that were shot.

As approximately half of the production from the field is coming from porous brown and gray magnesian limestone, it seems plausible that later in the productive life of the field, when reconditioning becomes imperative, production from the limestone may be greatly enhanced by acidization.

WELL SPACING

Well-spacing regulations in the North Cowden field require the drilling of one well on each 40-acre unit not closer to lease lines than 440 feet. To the present (September, 1938) there have been no exceptions to this order; however, there are many wells not drilled in the center of their respective units.

The lack of uniformity in pay thickness, variations within the porous beds, low order of permeability, effective pore space and saturation, and the high cost of drilling, substantiate the generally accepted belief that one well to a 40-acre unit is economically adequate. Those operators who advocate a denser drilling pattern may, ironically enough, to a certain extent, use the same reasoning process as the one evolved here; however, with curtailed allowables and fluctuating crude prices, any denser pattern at the present time would be virtually economic suicide.

PRORATION

Proration in its broadest sense covers field-regulation conservation measures, including mechanical equipment for wells in some extremely high gas-pressure fields, and designates the amount of oil to be taken daily from each well and from the field proper. State-wide regulation orders adaptable to oil fields are in the main regulative orders providing for good operative practice with a minimum of discrimination between the different fields. Blanket proration orders for any given field must of necessity be detrimental to some wells whose rate of flow is restricted below the most efficient rate.

Proration by the Railroad Commission of Texas has been applied to the North Cowden field since May, 1932, at a time when there were twelve wells in the field. Five factors enter into the calculation of well allowables. First, a 50 per cent acreage factor, the base being a 40-acre unit; second, 50 per cent of allowable based on initial 24-hour open-flow potential; third, wells with high gas-oil ratios are penalized. A well may produce daily that number of cubic feet of gas which the largest producer in the field would make, on the assumption that it had a gas-oil ratio of 3,500 cubic feet per barrel; in September, 1938, a well could not produce more than 325,500 cubic feet of gas daily

without being penalized. Fourth, the marginal allowable is 21 barrels per well, unless the well is penalized below this figure because of excessive gas-oil ratio; fifth, the field outlet is determined by allocation of the state market outlet.

METHODS OF PRODUCING WELLS

Flowing wells.—Most of the flowing wells at North Cowden produce 24 hours daily; however, an increasing number of wells must be stop-cocked or make their production over a period of a few hours a day.

Several wells have jet collars installed in the tubing to assist flow by permitting aeration of the fluid column with the gas which accumulates in the annular space.

Sixty-six per cent of the wells in the field are connected to the Cities Service natural-gasoline plant, which is of the absorption type, having a capacity of 50 million cubic feet per day, and is operated on well pressure. Additional wells could be tied in, but some will not flow against the 30- to 40-pound back pressure, which is required to be held on the trap for sale of gas.

Artificial-lift wells.—Three types of artificial lift were employed in 25 wells in September, 1938.

Seven wells are operated by flow valves without the injection of gas from an outside source.

One additional well is on gas lift with the gas being supplied from an adjacent well.

The remaining 17 wells are operated by individual pumping units. Power is furnished by gasoline or natural-gas engines. The average beam has a 12-foot, 10-inch working center and $\frac{3}{4}$-inch sucker rods. Length and frequency of stroke are different for each well. Eleven of these wells were put on the pump at completion.

PIPE LINE

The Humble Pipe Line Company gathers all oil produced in the North Cowden field. Present pipe-line facilities are entirely adequate to handle the daily output of the field, although in the past development was curtailed by lack of an assured outlet.

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PAGE FIELD, SCHLEICHER COUNTY, TEXAS[1]

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ABSTRACT

The Page field in south-central Schleicher County, Texas, is in the physiographic province known as the Edwards Plateau and is structurally near the southwest margin of the Eastern platform. Four gas wells and one oil well are producing from a porous limestone of Strawn age at depth varying from 5,370 to 5,730 feet. The limits of the field are as yet undetermined especially on the north. A pronounced structural feature developed in the Strawn limestone is reflected by much less pronounced folding in higher beds and is interpreted as a probable reef structure.

The Page field is in Schleicher County, Texas, about 9 miles southeast of the town of Eldorado and 45 miles due south of San Angelo. It is on the western edge of the Eastern platform and near the eastern edge of the Black Shale basin in the physiographic province known as the Edwards Plateau. It is approximately 70 miles west of the nearest outcrop of igneous rock of the Llano uplift.

The discovery wildcat of the Page field, Cooper Gas Company's Page No. A-1-40, was commenced by Geo. T. Wilson *et al.*, in November, 1929. This operator ceased drilling in January, 1931, at a depth of 5,055 feet. The well was taken over and deepened by John Cooper in May, 1934. Sweet gas with a distillate content of 0.7 gallon per 1,000 cubic feet, as condensed in separator, was struck in June, 1934, at a depth of 5,402 feet in a porous limestone believed by this writer to be Strawn in age, and drilling was continued intermittently to a total depth of 6,257 feet. The well was plugged back to 5,550 feet, and after being shot with 200 quarts of nitroglycerine at 5,400–5,445 feet, and after the gas zone was acidized with 3,000 and 8,000 gallons of hydrochloric acid, it was completed as a gas-distillate well in January, 1936. This well was initially gauged as producing at 6 million cubic feet of gas through separator and against a back pressure, but recent tests by the Railroad Commission indicate an absolute open flow of 16 million cubic feet.

There have been four gas wells, one oil well, and two dry holes drilled in this field to date, or a total of seven wells. All of these wells are located on the Bert Page ranch, and all belong to the Cooper Gas Company. All of these wells have been renamed and renumbered with

[1] Read before meeting of West Texas Geological Society, Midland, Texas, August 17, 1940. Manuscript received, September 30, 1941.

[2] Geologist, Cooper Gas Company and Cardinal Oil Company. The writer acknowledges with gratitude the help of various geologists of Midland, Texas, for valuable criticisms, and also the help of Gerry Phillips of the Cardinal Oil Company, San Angelo, for assistance in drafting.

the exception of the Lone Star Gas Company-Humble Oil and Refining Company's No. 2, a dry hole west of the field. The new numbers are used by the writer.

The gas potentials made by the United States Bureau of Mines method by W. C. Nye[3] of the four gas wells, together with top porosity data, are as follows.

Well Number	*Datum, Top of Porosity in Feet*	*Potential Gas Production, Million Cubic Feet*
1-A-40	−3,124	16
2-A-40	−3,142	110
1-B-31	−3,139	16
1-D-32	−3,090	28
Total potential gas		170

The heat value of the gas is about 1,200 British thermal units. The gravity of the distillate from the gas wells is 61°, and is nearly water-white in color.

The one oil well of the field, C-1-30, has a potential of 259.2 barrels of 37° gravity crude. It is now producing about 37 barrels daily, together with about 15 barrels of salt water.

The method of drilling and completing wells in the Page field has not followed any set rule. The discovery well was drilled with a standard rig. The Cooper Gas Company's Page No. A-2-40 was drilled with a Jumbo "J" spudder with gas string cemented on top of Strawn limestone, as were the Cooper Gas Company's No. C-1-30 and the Lone Star Gas Company-Humble Oil and Refining Company's No. 2. This necessitates about four strings of casing, but it is possibly a better method of completion, as the potential production of the Cooper Gas Company's No. 2-A-40 exceeds potentials of the other three gas wells combined. The well in Section 31 (Cooper No. B-1-31) and Cooper No. D-1-32 were spudded about 1,000 feet with spudder, 15½-inch casing was cemented below the fresh water at approximately 350 feet and a rotary rig was used to drill to the total depth. A Schlumberger test was then made and 7-inch casing cemented on bottom, after which the casing was gun-perforated opposite the porous zones, and the wells were acidized for completion.

At present, the only outlet for the gas is a 2-inch welded line to the city of Eldorado approximately 9 miles northwest of the field. The Lone Star Gas Company, has completed the laying of a 45-mile 8-inch welded line from the field to San Angelo to enable the Cooper Gas Company to fulfill its contract to meet the fuel requirements of the West Texas Utilities Company at its electric generating and water-pumping plant. This line will be in use soon.

[3] W. C. Nye, production superintendent for the Cooper Gas Company.

Despite the wide spacing of the wells drilled, the field is as yet undefined, especially at the north.

The section of rocks encountered in drilling the Cooper Gas Company's Page No. A-1-40 has been grouped in the following units.

Stratigraphic Units	*Depths (Feet)*	*Thickness (Feet)*
Cretaceous (Fredericksburg and Washita)	0–350	350
Permian (Clear Fork, Wichita [restricted] and Wolfcamp), predominantly limestone	2,130	1,780
Pennsylvanian (Cisco and Canyon), predominantly black shale	5,332	3,202
Pennsylvanian (Strawn and Bend), predominantly limestone	6,050	718
Ordovician (Ellenburger)	6,257 (T.D.)	207

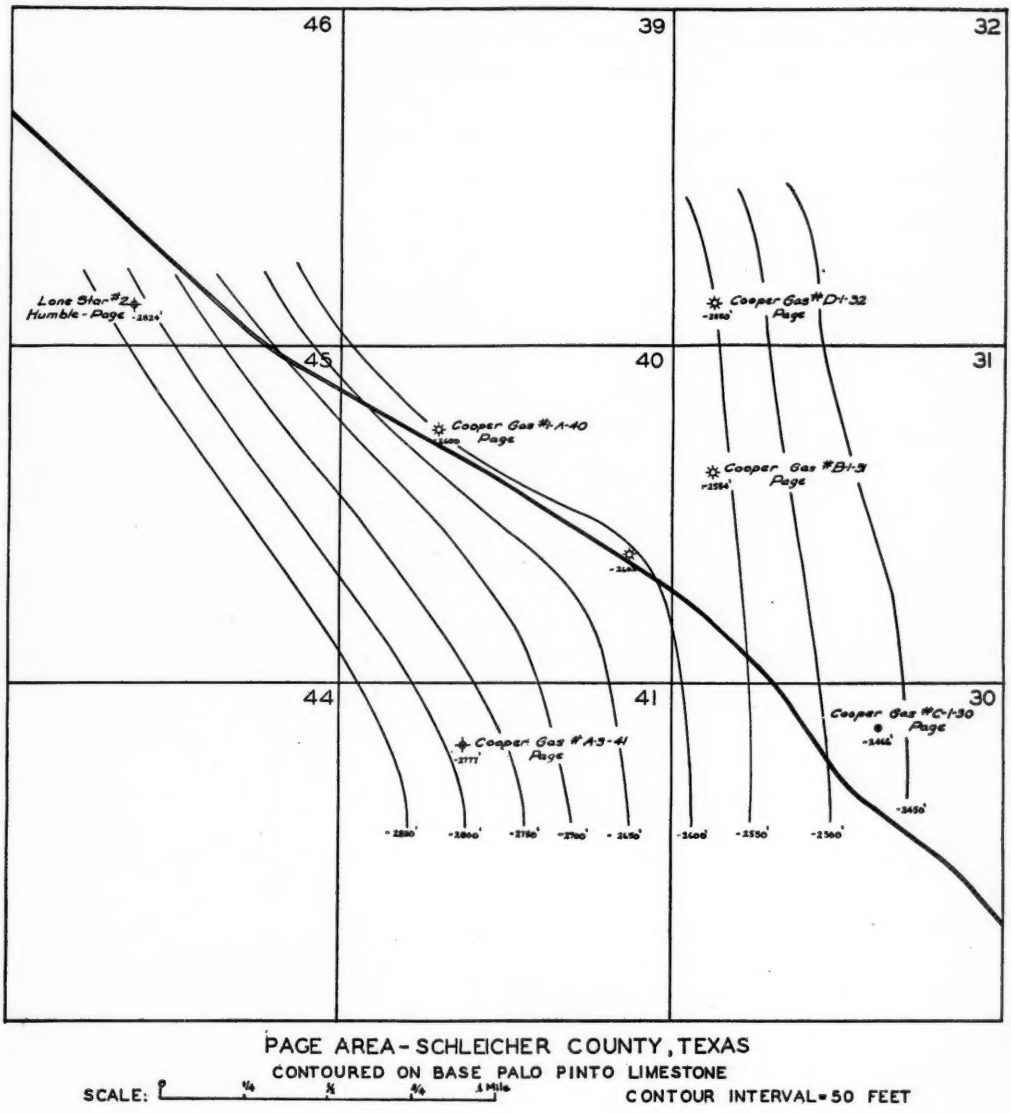
The top of the black shale is probably the best upper structural marker present. There is a definite lithologic change here.

Detailed surface mapping of the Cretaceous beds reveals a northwest-plunging irregularly shaped nosing structure. It is doubtful if the structure so outlined has more than a general significance since the underlying Permian and Pennsylvanian beds do not conform with the Cretaceous either locally or regionally.

The Permian section in the Page field consists mostly of limestone with some sandstone and a little shale. Some of the sandstone beds contain water and the sand and chert near the top of the black shale is water-bearing. A short distance southwest of the field the Permian limestone grades abruptly into gray and black shale. This abrupt gradation marks the boundary between the Eastern platform and the Black Shale basin. The regional strike of this facies change is northwest-southeast.

The top of the black shale, or top of the Cisco, reflects a gentle structure as compared with the top of the Strawn limestone.

At a depth of approximately 4,800 feet, there occurs a persistent limestone stratum about 100 feet thick, which the writer correlates with the Palo Pinto limestone. The so-called Palo Pinto limestone rises steeply toward the east from −2,824 feet in the Lone Star-Humble No. 2 to −2,466 feet in Cooper No. C-1-30 on the base of this limestone; or a rise of 358 feet in about 3 miles. Cooper Gas No. 1-A-40 and No. 2-A-40 in Section 40 have the same subsea elevation on the base Palo Pinto as have Cooper Gas No. D-1-32 and No. B-1-31. This causes a broad flattening effect in the north and east parts of Section 40, making a sort of terraced effect over the high part of the structure (Fig. 1). The interval between the base of Palo Pinto and the top of producing limestone varies from a "low" of 390 feet to a "high" of 803 feet (Fig. 2). This section consists mostly of black shale,



PAGE AREA - SCHLEICHER COUNTY, TEXAS

CONTOURED ON BASE PALO PINTO LIMESTONE

SCALE: 0 ¼ ½ ¾ 1 Mile

CONTOUR INTERVAL = 50 FEET

FIG. 1.—Page area, Schleicher County, Texas, contoured on base of Palo Pinto limestone. Contour interval, 50 feet.

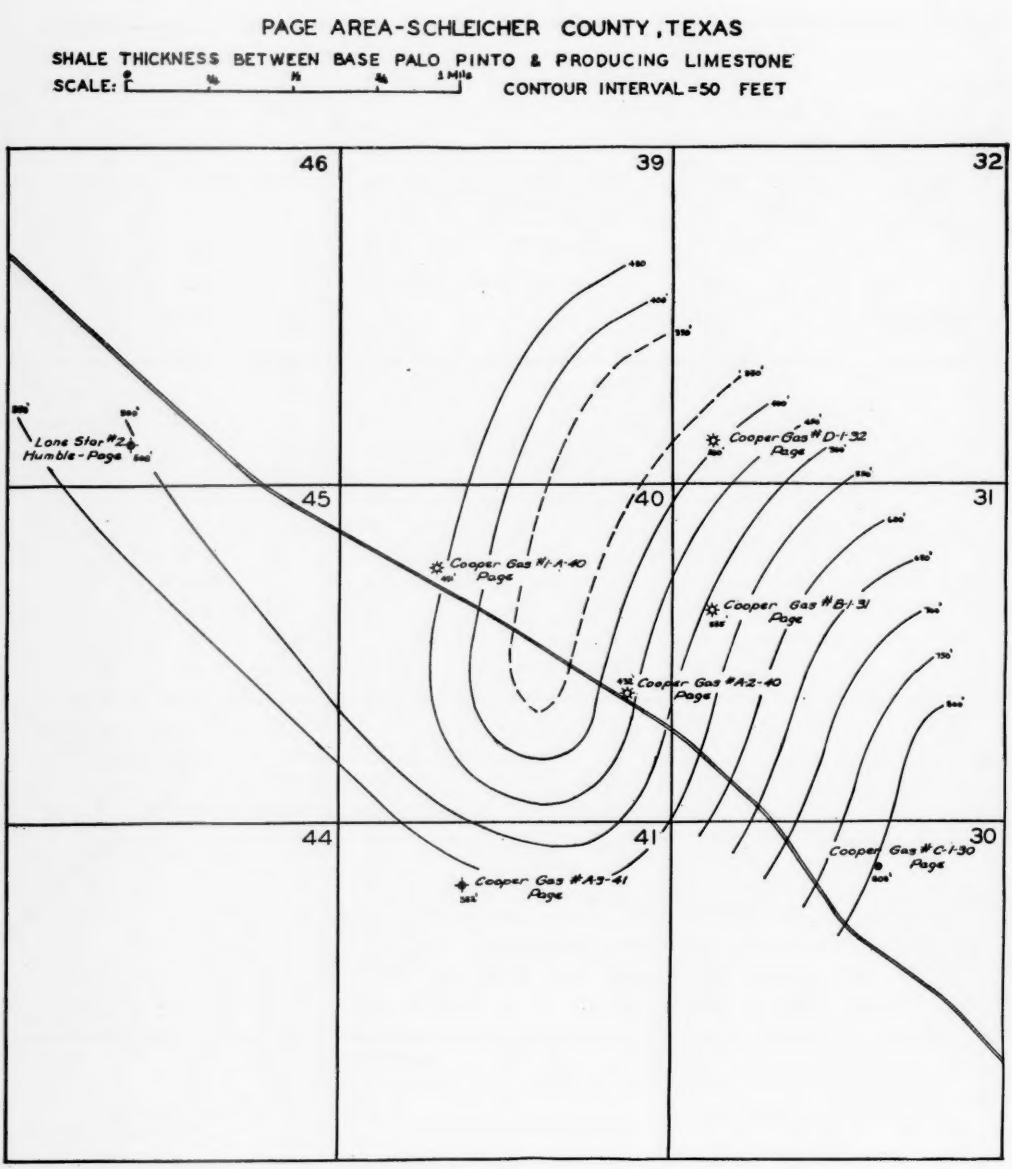


FIG. 2.—Map of Page area, showing thickness between base of Palo Pinto and producing limestone. Contour interval, 50 feet.

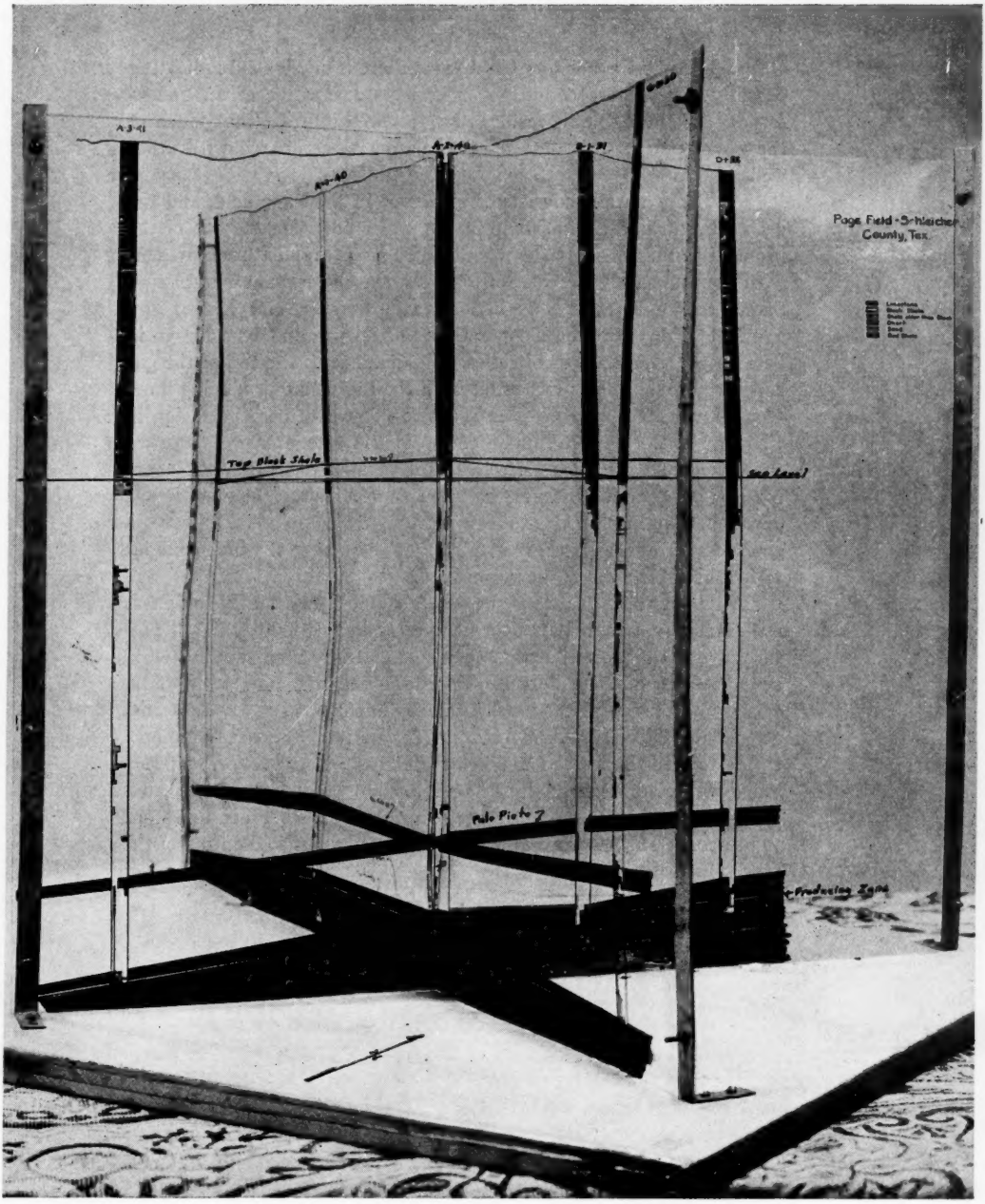


FIG. 3.—Photograph of cross section of Page field made on celluloid.

although in the Cooper Gas No. C-1-30 there is much sand indicating possibly a nearshore condition or perhaps suggestive of an unconformity, as the insoluble residues for this well indicate that much of the upper part of this limestone is missing as compared with other wells.

The Strawn series consists of limestone in the Page field, and the gas occurs in porous limestone in the upper part. On the top of the producing limestone, a rather pronounced structural feature is evident with approximately 400 feet of dip between Cooper Gas No. D-1-32 and Lone Star-Humble No. 2 in Section 46, a distance of $1\frac{3}{4}$ miles, and 339 feet of dip between Cooper Gas No. D-1-32 and No. C-1-30 in Section 30, a distance of $1\frac{3}{8}$ miles. The distance to the top of the gas zone or porous zone as measured from the top of the producing limestone is variable, ranging from a "low" of 50 feet of penetration in Cooper No. B-1-31 to a "high" of 170 feet in Cooper No. D-1-32. In the seven wells drilled to date, with the possible exception of Cooper No. B-1-31, there has occurred a black shale break slightly above the porosity. The insoluble-residue work already completed indicates a good marker of chalky chert with siltstone, the base of which is about 15 feet below the top of the porous zone.

From the foregoing, it is the writer's belief that the Page field is not primarily a fold, but rather a reef or depositional "high," possibly over an old positive area with some later folding as reflected in the flattening of the Palo Pinto limestone and the gentle apparently closed fold on top of the black shale. It is the writer's thought that after Palo Pinto time and prior to Cisco time, there was regional tilting toward the west. The black shale of the Cisco section was then laid down to a horizontal line and a later fold would have the effect of accentuating the Strawn structure, causing the Palo Pinto limestone to be arrested or flattened and a closed, less obvious fold on top of the black shale.

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SUMMARY OF FAUNAL STUDIES OF NAVARRO GROUP OF TEXAS[1]

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ABSTRACT

The Navarro group in east-central Texas is divided into four formations, in ascending order, Neylandville marl, Nacatoch sand, Corsicana marl, and Kemp clay. Recent paleontologic studies have resulted in the recognition in the group of 411 named species and varieties of the larger invertebrate fossils (exclusive of a few corals and crustaceans); in addition, more than 100 poorly and incompletely preserved forms are assigned to genera, but are too imperfect for specific identification. Of the 411 specifically named forms, 30 (7+ per cent) are known to range from beds of upper Austin age to the top of the Cretaceous. Fully 90 per cent of the Navarro fauna as at present known is restricted to the Navarro group and its equivalents. Only one species, *Gryphaeostrea vomer* (Morton), is known to range upward into sediments of Tertiary age.

The Neylandville marl has yielded about 102 specifically named forms; leaving the 30 long-ranging species out of consideration, only 5 or 6 of the remaining species range downward into the Taylor marl, whereas 33 species range upward into the Nacatoch sand. From these figures it is concluded that the fauna of the Neylandville is more closely related to that of the Navarro group above than it is to the fauna of the Taylor marl below, and justifies classifying the Neylandville with the Navarro. The other formations of the group have yielded specifically named forms as follows: Nacatoch sand, 245; Corsicana marl, 98; and Kemp clay, 105.

The failure of practically all of the Navarro species, and 50 per cent or less of the genera, to appear in post-Navarro sediments is interpreted to indicate that a major geologic episode took place at the end of Cretaceous time. An uplift of the land or a lowering of sea-level, of sufficiently great magnitude to cause the strand line to retreat across the continental shelf to its relatively steep outer slope, thus restricting the area of sea bottom suitable for the shallower-water organisms to a very narrow zone, and the consequent severe competition for space and food, is suggested as an adequate cause to explain the extinction of many organisms and the rapid evolutionary development of others.

The Navarro group is correlated with the Maestrichtian of Europe mainly on the common occurrence of the cephalopod genera *Sphenodiscus*, *Parapachydiscus*, *Discoscaphites*, and *Belemnitella*. Representatives of these genera have been recorded from late Upper Cretaceous sediments in widely separated parts of the earth.

The Navarro group is the uppermost major geologic unit of the Upper Cretaceous series of Texas. Its area of outcrop forms a relatively narrow, sinuous band extending from Red River in Bowie County in the northeast to the Rio Grande in Maverick County in the southwest. The group has been divided into four formational units, named in ascending order: Neylandville marl, Nacatoch sand, Corsicana marl, and Kemp clay. These units are all of marine origin. The sediments composing them are medium- to fine-grained and were deposited in

[1] Read before the Society of Economic Paleontologists and Mineralogists at Chicago, April 11, 1940. Manuscript received, October 7, 1940. Published by permission of the director of the Geological Survey, United States Department of the Interior, and of the director of the Bureau of Economic Geology, Austin, Texas. This paper is a brief summary of the results of a monographic treatment of the larger invertebrate fossils of the Navarro group of Texas, exclusive of a few corals and crustaceans, now in press as *University of Texas Publication No. 4101*.

[2] United States Geological Survey.

waters covering a continental shelf. The limiting depths of these waters have not been precisely determined, but the character of the fossil faunas suggests that the waters were not deeper than those of the Continental Shelf off the present Atlantic Coast, that is 100 fathoms or less. The prevailing massive bedding indicates, however, that in the main the deposits were laid down below the disturbing effects of wave action. An occasional shallowing of the water during Nacatoch and Kemp time is indicated by some cross-bedding, and by a few coquina-like shell layers. The general absence of coarse materials suggests that the clastic materials of the group were derived from a low land which must have been west and northwest of the belt of outcrop.

The Navarro group is limited at its base by an erosional unconformity that probably does not mark a very long interval of time. A stratigraphic break of importance at the base of the Corsicana marl is indicated by a phosphatic band, and by the southward transgression of this unit over the Nacatoch sand and over the Neylandville marl, cutting both of these formations out of the section for a distance of more than 200 miles in south-central Texas. There is some evidence, not considered conclusive, that a minor erosional break is present at the base of the Kemp clay. An unconformity interpreted to mark a stratigraphic break of major magnitude separates the Navarro group from the overlying Midway group; this break is indicated by physical evidence observed at many places, but its magnitude is indicated by paleontologic evidence. The emergences that caused these erosional breaks were each followed after a longer or a shorter period by quick submergence, for basal conglomerates are thin or wanting, and massive bedding follows within a few inches, or at the most, within a few feet, above the contacts.

The four formations of the Navarro group are all more or less fossiliferous in their different parts. Microörganisms, such as Foraminifera and Ostracoda, can be obtained from almost any sample; the larger invertebrate organisms are abundant in some layers and concretions, and are fewer or wanting in others. The statistics of occurrence and range given in this paper pertain to these larger fossils, which are mainly mollusks, with a few echinoids, worms, and brachiopods. Omitted from the present study are a few corals and crustaceans.

The collections under consideration have yielded 411 named species and varieties of the larger invertebrate organisms, many of which are new to science. Approximately 90 per cent of these forms are restricted in their known range to the Navarro group and its age equivalents in the Atlantic and Gulf Coastal Plain. Thirty species, or 7+ per cent of the fauna, have a long stratigraphic range from sediments of upper

Austin age below to those of uppermost Navarro age. These long-ranging species, together with many others which, though not identical are closely related, clearly indicate an unbroken succession of gradually changing faunas in the Upper Cretaceous series. The geographic and stratigraphic ranges of the genera and species are shown in 6 large folding tables that accompany the monograph.

The Neylandville marl has yielded 102 named species and varieties of the larger invertebrates, including 1 species of Vermes, 1 of Echinodermata, and 100 species and varieties of Mollusca; of the Mollusca 43 are Pelecypoda, 3 are Scaphopoda, 38 are Gastropoda, and 16 are Cephalopoda. Excluding the 30 long-ranging species from consideration, 5 or 6 of the Neylandville forms range downward into the upper part of the Taylor marl, and 33 range upward into the Nacatoch sand. This greater number of upward-ranging forms is one of the chief reasons for classing the Neylandville marl with the Navarro group, rather than with the underlying Taylor marl, where most of the students of micropaleontology are wont to place it.

The named species and varieties recorded from the Nacatoch sand number 245. This exceeds by 140 the greatest number recorded from any one of the other three formations of the group. It is perhaps unsafe to conclude from this greater number of forms that the sandy bottom of the Nacatoch sea offered an exceptionally favorable environment for the existence of the organisms; their greater number may be due to more favorable conditions of preservation. Most of the Nacatoch fossils have been obtained from hard, calcareous concretions in the sand, many of the shells therein being almost perfectly preserved; whereas adjacent unconsolidated sand at the same level as the concretions may be barren of the larger fossils. This suggests that fossils once present in the loose sands have been dissolved away by circulating waters, leaving no trace of their former presence, and further suggests that the number of fossils recoverable from a formation may not necessarily be a fair measure of the organisms that lived in the sea at the time the containing sediments were deposited. The species and varieties of the larger invertebrate fossils of the Nacatoch are distributed as follows: Vermes, 4; Echinodermata, 1; Molluscoidea, 1; and Mollusca, 239. The Mollusca include 106 Pelecypoda, 4 Scaphopoda, 106 Gastropoda, and 23 Cephalopoda.

Ninety-eight named species and varieties are listed from the Corsicana marl; this is the smallest number recorded from any of the formations of the group. These forms include: Porifera, 1; Vermes, 5; Echinodermata, 5; Mollusca, 87. The Mollusca include 64 Pelecypoda, 18 Gastropoda, and 5 Cephalopoda.

One-hundred and five species and varieties credited to the Kemp clay are distributed as follows: Porifera, 1; Vermes, 3; Molluscoidea, 2; Mollusca, 99; of the Mollusca 44 are Pelecypoda, 3 are Scaphopoda, 46 are Gastropoda, and 6 are Cephalopoda.

A certain number of the species recorded from each of the four formations of the group are restricted in known range to the one formation; the others range to underlying or to overlying formations. The faunal differences that distinguish the successive formations of the group are due, in part to facies differences of the sediments, in part to evolutionary changes, in part to extinction of genera and species, and in part to immigrants from other seas.

Of the 411 species and varieties of the larger invertebrate fossils recognized in the Navarro fauna as a whole, only one, *Gryphaeostrea vomer* (Morton), is known to range upward unchanged into beds of Tertiary age, and even it has not been recorded from the Tertiary of Texas. Considered from the standpoint of genera: of 192 genera recognized in the Navarro group, about 65 (34 per cent) are known to range upward into the Tertiary, leaving 127 (approximately 66 per cent) restricted below the Cretaceous-Tertiary boundary. Since some genera disappeared from the section in the formations of the group below the Kemp clay a more accurate measure of the magnitude of the faunal break may be had by comparing the fauna of the Kemp clay alone with that of the overlying Tertiary. If the actual number of genera recognized in the Kemp be considered, only about 33 per cent pass upward into the Tertiary, but if account be taken of additional genera that might be expected to be present in the Kemp, because they are known both in older formations of the group, and in the overlying Tertiary, as many as 50 per cent of the genera would pass into the Tertiary.

Among the better known forms that became extinct at the end of the Cretaceous may be mentioned the worm, *Hamulus;* the echinoids, *Cardiaster*, *Hemiaster*, and *Micraster;* the mollusks, *Inoceramus*, *Exogyra*, 3 subgenera of *Pecten*, 3 subgenera of *Cardium*, all of the rudistids, and all of the ammonites.

An episode in geologic history that could cause the disappearance from the section of 410 out of 411 species of the larger invertebrates, and fully 50 per cent of the genera, must be classed as one of major importance. The paleontologic evidence seems to indicate that the faunal changes associated with the Cretaceous-Tertiary unconformity were far greater than those that transpired during the long interval represented by the combined Austin, Taylor and Navarro units for, as already stated, at least 30 species lived throughout that time with-

out marked evolutionary change, whereas only one species survived the Cretaceous-Tertiary episode.

Time alone, unassisted by other factors, does not seem adequate to account for the known faunal changes that took place during the Cretaceous-Tertiary interval. It does not seem conceivable that this interval could have been long enough in the Gulf region to allow normal, unstimulated evolutionary processes to produce these changes. However, the apparent absence of sediments of Danian age seems to indicate that the interval was long enough to include Danian time, and that the unconformity, therefore, represents something more than a minor lapse of geologic time.

If the Cretaceous-Tertiary unconformity represented an important time interval in the Gulf region, as the evidence seems to indicate, the time represented by the same unconformity in the Atlantic Coastal Plain must have been much longer, for there sediments of both Kemp and Midway ages are missing from the section, allowing sediments not older than the Wilcox to rest directly on Upper Cretaceous sediments not younger than the Corsicana marl.

A slight cooling of the climate in late Cretaceous time has been invoked by Schuchert and Dunbar, and others, as a factor contributing toward the extinction of genera and species. No such cooling is apparent in the Gulf region, for rudistids, supposedly indicative of climate not cooler than warm-temperate, are recorded from beds near the top of the Kemp, and Julia Gardner has said of the overlying Midway fauna that it lived under warm or warm-temperate climatic conditions. Acceptance of the theory of climatic cooling would seem to imply, therefore, a Cretaceous-Tertiary erosion interval long enough to allow for a change from a warm-temperate to a cooler climate after the deposition of the Kemp sediments, and back again to a warm-temperate climate before the deposition of the Midway sediments.

An explanation that seems to account most satisfactorily for the known faunal changes is one that postulates an emergence of the land, or a lowering of sea-level, at the end of Upper Cretaceous time, such that the strand line retreated to the relatively steep outer slope of the Continental Shelf, throughout the length of the Atlantic and Gulf Coastal Plain. An idea of the effect of such a change can be had by imagining a lowering of the present sea-level to the 100-fathom contour. Instead of the broad Continental Shelf of less than 100 fathoms depth bordering the Atlantic shoreline, the sea bottom of corresponding depth would be the exceedingly narrow strip on the outer slope of the shelf, that now lies 100–200 fathoms below sea-level. Into this drastically restricted zone would be crowded the multiplicity of

organisms that had been maintaining a lazy existence in the salubrious waters of the broad Continental Shelf. Competition would be severe and all those unfortunate forms that could not adapt themselves to the new and cramped living conditions would perish in the struggle. We do not know much about the continental shelf of late Cretaceous time, but some similar narrowing-down of the area suitable for the existence of shelf-living organisms may well have taken place then.

Assuming the correctness of this suggested explanation, we of course have no way of knowing just how long the struggle may have continued in the restricted zone, but the completeness of the change effected in the faunal assemblage suggests that it must have continued for a considerable stretch of geologic time. The competition stimulated evolution, and the forms that survived the struggle were changed creatures when, with the later advance of the Midway sea, they finally returned to the ancestral home. So greatly were they changed in form and surface features that their fossil remains now found in the sediments of the Midway group must be classed as specifically different from those found in the underlying late Cretaceous sediments. Along with these changed forms came also immigrant strangers from other seas, adding thus to the marked differences that distinguish the Midway fauna from the older Navarro fauna.

Most students of Coastal Plain stratigraphy have recognized the magnitude of the Cretaceous-Tertiary erosion interval, but a few have doubted its importance. The argument has been offered that the similarity in character and origin of the sediments below and above the Navarro-Midway contact is evidence that the interval separating them is relatively unimportant. There is a general similarity in the sediments composing the Kemp and Midway units, and in places, as in Williamson County, the shaly clays below and above the contact are so much alike that they can scarcely be told apart, except by the finding of diagnostic fossils. Actually the presence of such totally different assemblages of fossil species in similar sediments on opposite sides of a stratigraphic break is a strong argument in favor of the importance of that break. If the erosion interval were short the existence of similar ecologic and climatic conditions before and after the interval would justify the expectation that the faunal content above the contact would show a close relationship to that below it. When, instead, a profound faunal change is found to have taken place, surely one is bound to conclude that the physical break marks some great episode in the geologic history of the region.

The Navarro group is correlated with the Maestrichtian of Europe on paleontologic evidence afforded mainly by genera in the cephalopod

class. In North America, Europe, and elsewhere there is a common succession of ammonite genera in sediments of the Cretaceous system. At the top of this succession are found several cephalopod genera of which the more common ones are the ammonites *Discoscaphites*, *Sphenodiscus*, and *Parapachydiscus*, and the belemnite *Belemnitella*. All four of these genera are present in the Navarro group. Closely related representatives of these genera are found in widely separated parts of the earth. In some cases the representatives are so much alike that they have been called by the same specific names. *Parapachydiscus gollevillensis* (D'Orbigny) is an example. In Europe this assemblage is found in the Maestrichtian unit and its age equivalents. The type locality is near Maestricht in Holland. The world distribution of marine sediments of Navarro age (Maestrichtian), as shown on a small-scale map accompanying the monograph, is based mainly on the recorded occurrence of one or more of these genera. These sediments are recognized in parts of the Atlantic and Gulf Coastal Plain of the eastern United States, the Western Interior of the United States and Canada, California (questionably), eastern Mexico, Central America, the West Indies, South America, Graham Land in Antarctica, Europe, northern Africa, southwestern Asia, India, Madagascar, and Japan.

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ANALYSIS OF MIDWAY FAUNA OF WESTERN GULF PROVINCE[1]

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ABSTRACT

The known fauna of the Midway of the western Gulf province includes, roughly, 47 genera of Pelecypoda, 2 of Scaphopoda, 65 of Gastropoda, 1 of Cephalopoda, and 1 genus of Vermes that has been commonly referred to the Gastropoda. For the purpose of determining the relationships of this Paleocene fauna to those which precede and follow, the genera may be segregated into more or less clearly defined assemblages: (1) genera recorded in the Midway that have persisted from the Cretaceous to Recent time; (2) those restricted to the Cretaceous and Paleocene; (3) those restricted to the Cretaceous and early Tertiary; (4) those restricted, at least in the Gulf province, to the Paleocene and early Eocene; (5) those restricted to the Paleocene and Eocene; (6) those restricted to the Paleocene, Eocene, and Oligocene; (7) those initiated in the Paleocene and continuing to the Recent.

In the Midway fauna of the western Gulf province,[3] about 47 superspecific groups of pelecypods and about 65 of gastropods, 2 of scaphopods, 1 of cephalopods, and 1 of Vermes have been recognized. No single species in the Gulf province is certainly known to bridge the rift between the Cretaceous and the Tertiary. The value of the superspecific groups in determining the relationships of the Paleocene fauna to those which precede and follow, vary widely. They may be segregated into seven more or less clearly defined assemblages, as follows.

1. Genera and subgenera recorded in the Midway which have persisted from Cretaceous to Recent time. This number, which includes about 43 per cent of the pelecypods, but only about 22 per cent of the gastropods, would, if it were possible to place the old Tertiary species as accurately as the Recent, be greatly diminished. The major groups are already diversified at the opening of the Tertiary, but the characters, largely internal, on which the separations are made, are commonly lost in the older shells.

Two subgroups may be recognized as follows.

a. Genera and subgenera persisting in the Gulf province from Cretaceous to Recent time: *Nucula* (*sensu lato*), *Limopsis*, *Glycymeris*, *Volsella*, *Lithophaga*, *Pteria*, *Anomia*, *Ostrea*, *Periploma*, *Cuspidaria*, *Crassatellites*, and *Corbula; Dentalium* and *Cadulus* (*sensu lato*); *Mathilda*, *Polinices*, *Xenophora*, *Architectonica*, and possibly *Granosolarium*, *Turritella*, and *Ringicula*.

[1] Read before the Society of Economic Paleontologists and Mineralogists at Chicago, April 11, 1940. Manuscript received, October 7, 1940. Published by permission of the director of the Geological Survey, United States Department of the Interior, Washington, D. C.

[2] United States Geological Survey.

[3] Julia Gardner, "The Midway Group," *Univ. Texas Bull. 3301* (June, 1935). 403 pp., 28 pls.

b. Genera persisting from the Cretaceous to the Recent, but not present in the Recent fauna of the Gulf: *Pholadomya* is essentially a Mesozoic genus, although the genotype is a deep-water West Indian form. The Recent *Plicatula* are for the most part oriental, the Recent *Astarte*, boreal. *Pseudoliva* and *Ancilla* are essentially Paleocene and Eocene, although the genotype of *Ancilla* is a Recent species from the Indo-Pacific; the genotype of *Pseudoliva* is a Recent species from the northwest coast of Africa. *Corbicula*, a non-marine group widely recorded in the Upper Cretaceous of the western interior and sparsely represented in the Gulf Tertiary, is typified by a Recent shell from the Euphrates, and the Recent species are confined to the rivers and lakes of the East. *Mesalia*, essentially an Eocene genus, though not recorded from the western hemisphere in pre-Tertiary faunas, is reported from the Cretaceous of India by Stoliczka; the genotype is a Recent species from off the northwest coast of Africa. *Pinna*, widespread in the Cretaceous faunas and recorded from the east and west coasts and from the interior, has escaped observation in the Midway of the western Gulf but is locally common in the lower middle Eocene of the western Gulf and may be present in the Paleocene in the eastern Gulf. *Trachycardium* has been recognized in the Navarro and in the Paleocene of the Paris Basin and may be indicated by fragmentary material from the Paleocene of the Gulf. The high percentage of long-ranging pelecypods, particularly among the more primitive groups, is noteworthy. The ability of the simpler organisms to survive, while the more complex and highly specialized forms may perish, is a common, but not well understood, phenomenon.

2. A single genus, *Breviarca*, restricted to the Cretaceous and Paleocene but with strong Cretaceous affinities: The type is from the Upper Cretaceous of New Jersey. *Breviarca* is widespread in the Upper Cretaceous of the east coast and Gulf and, excepting for a few individuals in the Kincaid, is not recognized in post-Cretaceous faunas. *Breviarca*, if found alone, would be considered evidence of the Cretaceous age of the strata. There is no other genus in the Midway fauna open to a similar interpretation.

3. Genera and subgenera restricted to the Cretaceous and early Tertiary: *Tubulostium*, an excellent horizon marker in the basal Paleocene of the Gulf, is rather widespread south of the Equator during the Upper Cretaceous, and is common in the London clay, lower Eocene, of southern England. *Idonearca* is prolific and widely distributed in the Upper Cretaceous, Paleocene, and lower Eocene from New Jersey southward through the Gulf, on the west coast of North America, and the east coast of South America, and is widespread in Europe but

not in Africa. *Gryphaeostrea*, widespread at the top of the Cretaceous and the base of the Paleocene, is represented by a single species in the late Eocene of the Gulf. *Gyrodes*, a common Cretaceous genus with a few Paleocene species, survives in the lower Eocene of the Paris Basin, but these later forms are segregated under the subgenus, *Sigaretopsis*. *Calyptraphorus* is essentially an Eocene genus with a meager representation in the Paleocene of the Gulf province and in the Cannonball of the western interior. It is reported from the Cretaceous of India. *Volutocorbis*, widely established in the Paleocene with a few straggling species in the later lower Tertiary of the Gulf and the Paris Basin, is recorded by Morley Davies from the Cretaceous. *Exilia*, foreshadowed in the Cretaceous both of the Gulf province and of Europe, is widely, though not abundantly, distributed in the Paleocene of Europe and America. In the Gulf province it is confined to the Cretaceous, the Paleocene and the lower Eocene, but is reported from the later Eocene of the west coast by Stewart. *Tornatellaea* is recorded in the Upper Cretaceous and Paleocene of the east and west coasts and in the lower Eocene of the Gulf province. The distribution of *Hercoglossa* is practically coextensive with that of the Danian and Paleocene strata.

4. Genera and subgenera restricted, at least in the Gulf province, to the Midway and Wilcox: *Ledina*, excepting for a west coast middle Eocene species, is recorded only from the Midway of the Gulf. *Carinacca*, or a group closely resembling it, is restricted to the Midway of the western Gulf; *Lacunaria*, to the Paleocene of the Gulf and the west coast and the Wilcox of the Gulf; *Eoathleta*, to the Paleocene and lower Eocene of the Gulf; *Gilbertina*, to the Midway of Alabama and Texas, and to the Paleocene of France and Denmark.

5. Genera and subgenera restricted to the Paleocene and Eocene. *Calorhadia* and the subgenus *Litorhadia* are foreshadowed in the Paleocene but are particularly characteristic of the Eocene of the Gulf province; *Venericor* is typified by *Venericardia planicosta*, and that species with its close associates is the sign post of the Paleocene and Eocene in the western and the eastern hemispheres; *Campanile*, though characteristic of the Paris Basin, occurs also in the Paleocene of Brazil, Alabama, and California; *Priscoficus* and *Perissolax*, both culminating in the early Tertiary, are known subsequent to the lower Eocene only by the subgenus *Fulguroficus*, which persists into the Miocene in southern Europe; *Laevibuccinum* and *Mazzalina* are sparsely but rather widely distributed in the Paleocene and Eocene; *Falsifusus*, *Coronia*, and *Levifusus*, increase in prominence from the Paleocene to the middle and upper Eocene; *Surculites* and *Scaphander* (*Mirascapha*), though rather widely distributed from the Paleocene to the close of the Eocene, are not common at any time or place.

TABLE I

Range of Selected Genera in the Midway Molluscan Fauna

Partial list of genera in the Midway fauna	Cretaceous	Paleocene (Midway)	Eocene			Oligocene	Miocene	Pliocene	Quaternary
			Lower	Middle	Upper				
Nucula	+								
Limopsis									
Glycymeris									
Volsella	+								
Lithophaga	+								
Pteria	+								
Plicatula	+								
Anomia	+								
Ostrea	+								
Pinna	+								
Periploma									
Pholadomya	+								
Cuspidaria	+								
Corbicula									
Asaarta	+								
Crassatellites									
Trachycardium									
Corbula	+								
Dentalium									
Cadulus									
Mathilda									
Polinices									
Xenophora									
Architectonica									
Granosolarium	?-								
Turritella	+								
Mesalia	?-								
Pseudoliva	?-								
Ancilla	?-								
Ringicula									
Breviarca									
Tubulostium									
Idonearca	+								
Gryphaeostrea									
*Gyrodes (Sigaretopsis)									
Calyptrephorus	?-								
Volutocorbis									
Exilia	?-								
Tornatellaea									
Hercoglossa									
Ledina									
Carinacca?									
Lacuneria									
Eoathleta									
Gilbertina									
Calorhadia									
Litorhadia									
Venericor									
Campanile									
Priscoficus									
Perissolax									
Laevibuccinum									
Mazzalina									
Falsifusus									
Coronia									
Levifusus									
Surculites									
Scaphander (Mirascapha)									
Tritiaria									
Caricella									
Orthosurcula									
Saccella									
Glyptoactis									
Nemocardium	?- ?-								
Callocardia									
Teredo									
Fuphus									
Solariorbis									
Bittium									
Lyria									
Olivella									

*Gyrodes s. s. is confined to the Cretaceous, Sigaretopsis to the Paleocene.

6. Genera and subgenera restricted to the Paleocene, Eocene, and Oligocene: *Tritiaria*, *Caricella*, and *Orthosurcula*, all culminate in the middle or upper Eocene.

7. Genera and subgenera initiated in the Paleocene, continuing at least to the late Tertiary, and, for the most part, to the Recent Gulf fauna. *Solariorbis* is apparently restricted to the Tertiary, but *Bittium* and *Lyria* are sparsely distributed in the warmer waters, and *Olivella* is prolific on the sandy beaches of the Recent tropical seas.

In Table I, the list of genera first recorded in the Paleocene and persisting in the Recent faunas has been greatly abbreviated, but even if all genera were included, the list would be shorter relatively and less significant than similar lists in the later series. The major groups of the Mollusca were established before the opening of the Tertiary, and the Paleocene molluscan fauna is notable rather for the elimination of many of the elements conspicuous in the greater molluscan faunas of the Mesozoic than it is for important new elements which have their beginning in the Paleocene and become increasingly prominent through the Tertiary to the Recent seas.

In a study of the specific groups of the Midway, the provincial character of the faunas is apparent. They seem to have developed along a shore line intercepted by barriers which partially isolated the faunas and encouraged local evolution. The superspecific groups, on the other hand, seem extraordinarily cosmopolitan. Land bridges have been requisitioned to account for the similarity between the Paleocene faunas of northern Africa and those of Brazil, but the faunal characters common to Brazil and northern Africa are in large measure shared by the Midway assemblage of the East Coast and Gulf provinces. The Trinidad fauna, first described from the Soldado section by Miss Maury, and later recognized at other localities in Trinidad and in Venezuela, is perhaps as close to the Midway fauna as is the Recent fauna of the Gulf to that of northern South America. At some stage in the development of the Paleocene faunas, but probably for a short time only, there may have been an open water-way connecting the warm waters of the western Atlantic and the eastern Pacific oceans. The forms common to the east and west coast Paleocene faunas are, many of them, of no significance because of their wide distribution, or they are known from the New World only. Those reported, however, from the west coast and from both sides of the Atlantic indicate a migration from east to west. The place of origin and development of the Midway fauna is not known, but there is little reason to suppose that it stemmed *in situ* from the prolific and well understood Navarro fauna. Judging from illustrations alone, the Upper Cretaceous fauna

of the Libyan Desert (northeastern Africa) includes species more suggestive of the Paleocene than any observed in the Navarro. *Cardita baronetti* Pervinquière, for example, and its possible synonym, *Cardita libyca* Zittel, are strikingly similar to the Eocene Venericors, particularly to the species from the Montian of Belgium, which in turn resembles and is probably synchronous with a Midway species. Though widely scattered occurrences of closely related forms do not reveal the place of origin or the dispersal routes, they do clearly increase the probable duration of the interval between the eclipse of the thriving Navarro fauna and the establishment of the Midway assemblage. Not only must time be granted for the evolution of the Paleocene fauna, but it must be widely dispersed in two hemispheres.

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SIMPSON GROUP OF ARBUCKLE AND WICHITA MOUNTAINS OF OKLAHOMA[1]

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ABSTRACT

Several detailed sections are presented which are available because of comparatively recent road cuts. Also, in restudying some of the old sections, new information is presented indicating some changes in formation contacts, relative thickness of formations, and extension of the Tulip Creek formation farther eastward. Additional evidence is presented to justify more fully the earlier omission of Falls as a formation name for the Simpson group.

INTRODUCTION

Deep interest in the Simpson group manifested for many years has been steadily increasing. This interest is due to the various oil and gas formations that it contains over wide areas, to its asphalt deposits, its excellent glass sand, and to its numerous fossils which make possible local and widespread correlations.

Considerable new information has been secured on the Simpson group since *Bulletin 55*[3] of the Oklahoma Geological Survey was published in 1931. In several localities new road cuts have exposed the rocks, making excellent detailed sections available. These road sections occur along Falls Creek 5 miles south of Davis in the eastern edge of Sec. 32, T. 1 S., R. 2 E., on Highway 18 a mile south of Sulphur in Sec. 11, T. 1 S., R. 3 E., and Highway 48 in Sec. 12, T. 1 N., R. 6 E., about 17 miles southeast of Ada. Three other sections have been restudied, one east of Pooleville in Sec. 6, T. 2 S., R. 1 W., on West Spring Creek, and two southwest of Ardmore at the north and south ends of the Criner Hills in Secs. 16 and 35, T. 5 S., R. 1 E. In this restudy several changes have been made in the position of contacts of some of the formations and the changes in these contacts have affected the thickness of some of the formations, especially along West Spring Creek.

A new graphic section is included which recognizes the presence of 22 feet of the Tulip Creek formation along Highway 48 southeast of Ada, and changes in thickness of formations along West Spring Creek. A revised table gives thickness of formations in 9 sections.

[1] Manuscript received, October 15, 1941. Published by permission of the Oklahoma Geological Survey.

[2] University of Oklahoma, department of geology.

[3] C. E. Decker and C. A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull. 55* (1931), pp. 6 and 7.

ACKNOWLEDGMENTS AND EARLIER PUBLICATIONS

In addition to recognition given for assistance received in the earlier study of the Simpson group, the writer desires to acknowledge with gratitude the assistance given by Alfred Loeblich in measuring new sections and to Robert H. Dott and other members of the Oklahoma Geological Survey staff for helping to prepare the manuscript for publication. Part of the field expenses were paid by a grant from the University of Oklahoma research fund.

Earlier publications are listed in *Bulletin 55* of the Oklahoma Geological Survey.[4] Also, the distribution, topography, and drainage are described in that publication.

STRUCTURE

The complexity of the structure was indicated in the former publications, but more recent studies have greatly emphasized this complexity which has been seen more fully and in greater detail by aerial photographs. C. W. Tomlinson has shown that several of the major structures are scissor faults, also that the smaller faults are much more numerous than any one had anticipated.

STRATIGRAPHY

The subdivision of the Simpson group into five formations[5] is retained as used in *Bulletin 55* of the Oklahoma Geological Survey. These formations, as shown on the graphic section and in Table I from oldest to youngest, are: Joins, Oil Creek, McLish, Tulip Creek, and Bromide. A brief discussion of each of these formations is given supplementing those in the former publication.

JOINS FORMATION

The Joins is developed chiefly in the western and middle parts of the Arbuckle Mountains and at the north end of the Criner Hills. It

[4] C. E. Decker and C. A. Merritt, *op. cit.*

[5] Besides Falls, the use of which is discussed later in this paper, Ulrich[6,7] has added two other formation names, Criner and Cool Creek, to the upper part of the Simpson group. It is thought that adequate evidence has not been presented to justify the use of these additional formation names and in suggesting them, sufficient consideration has not been given to the marked fossil zones which characterize the Bromide formation in the Arbuckle Mountains and in the Criner Hills. Furthermore, Ulrich[8] has later listed Cool Creek as one of the formation names in the Arbuckle group.

[6] E. O. Ulrich, printed table entitled, "Amended Classification of Decker's 1931 Simpson Sections, December, 1932."

[7] *Idem*, abstract, "Simpson Group of Oklahoma," *Bull. Geol. Soc. America*, Vol. 44, Pt. 1 (1933), p. 105.

[8] E. O. Ulrich and G. Arthur Cooper, "Ozarkian and Canadian Brachiopoda," *Geol. Soc. America Spec. Paper 13* (1938), p. 32.

TABLE I

CORRELATION OF FORMATIONS OF SIMPSON GROUP WITH THICKNESS OF FORMATIONS, BASAL SANDSTONES, "BIRDSEYE-LIKE" LIMESTONES, IN FEET, IN NINE SECTIONS

General Eastern Section		1 *West Spring Creek*	2 *Ardmore-Davis Highway 77*	3 *Falls Creek*	4* *Highway 18, Mile South of Sulphur*	5 *Nebo, Southwest of Sulphur*	6 *Highway 48, 16 Miles SE. of Ada*	7 *North End, Criner Hills*	8 *Rock Crossing, Criner Hills*	9 *Type Section, Bromide*
Black River —?—	Name	Bromide	Bromide	Bromide	Bromide	Bromide	Bromide	Bromide	Bromide	Bromide
	Thickness	674.5	427.5	321.4	87.6 (exposed)	422.61	230.6	363.3	315.01	128.16 (exposed)
	Basal sandstone	92 (4)	52 (2)	28 (4)	10.3	40	26.5	24.2	20±	
	Name	Tulip Creek	Tulip Creek	Tulip Creek		Tulip Creek	Tulip Creek	Tulip Creek	Tulip Creek	
	Thickness	334.5	394.5	313.1		445.35	22.15	485.5	88.69	
	Basal sandstone	150	166	187.7		175	6.00	9		
	Name	McLish	McLish	McLish	Present	McLish	McLish	McLish		
	Thickness	447.67	475.33	164 (ex.)		392.7	75 (ex.)	437.7		
	"Birdseye-like" limestone	—	—	—	—	—	49**	94		
	Basal sandstone	30±	55			200±				
CHAZY	Name	Oil Creek	Oil Creek		Present	Oil Creek		Oil Creek		
	Thickness	627.33	681.5			660.0		558.8		
	Basal sandstone		19			220±				
—?— Beekmantown	Name	Joins	Joins			Joins		Joins		
	Thickness	149.17	294.17	Covered		200±	Wanting	198.8		
	Conglomerate	.33	1					.66		
	Total thickness	2,233.17	2,273			2,120.66		2,044.1		

* McLish and Oil Creek formations are exposed southward along the highway but structural relations are very complex.
** Five times this much one-half mile east of the highway.

is entirely wanting in the eastern part of the mountains where the basal sands of the Oil Creek rest directly on the upper limestones of the West Spring Creek formation of the Arbuckle group.

The Joins consists chiefly of thin limestones, some of which are shaly. It has a thin conglomerate at the base and a few other conglomerates within it at various intervals above the base. Some narrow zones are fossiliferous, containing graptolites, brachiopods, pelecypods, gastropods, and ostracodes. However, the most important fossils in this formation are the graptolites which form the *Didymograptus artus-bifidus* zone. In numerous sections this zone varies from 43 feet to nearly 200 feet above the base of the Joins. This seems to indicate that a more marked hiatus occurs between the top of the West Spring Creek formation and the base of the Joins where the graptolite zone is relatively near the base of the formation and suggests the absence of about 150 feet of basal beds of the Joins. This *D. artus-bifidus* zone in the Joins is about 900 feet stratigraphically above the important *D. protobifidus* zone in the West Spring Creek formation and about 2,000 feet below the *Amplexograptus maxwelli* zone in the upper part of the Bromide formation.

Elles[9] has shown that this graptolite zone of the Joins occurs at the top of 10 zones and subzones of graptolites in the Skiddaw slates of England. Benson and Keble[10] have indicated the presence of *D. artus* in the lower Castlemainian of New Zealand.

OIL CREEK FORMATION

The Oil Creek formation is well developed in all parts of the Arbuckle Mountains and at the north end of the Criner Hills. Its greatest thickness of 681.5 feet is along U. S. Highway 77, although it is nearly that thick on West Spring Creek and in the Nebo section south of Sulphur. It consists of limestones, sandstones, and shales. Limestones predominate in the middle and western parts of the mountains and sandstones in the eastern part. The reclassification of the West Spring Creek section credits the formation with a normal thickness of 627.3 feet rather than the exceptional amount given it before. The sandstones decrease from more than 200 feet in the eastern part to narrow stringers in the western part, and the limestones increase in thickness from about 20 feet in the eastern part to more than 500 feet in the western part.

[9] Gertrude L. Elles, "The Lower Ordovician Graptolite Faunas with Special Reference to the Skiddaw Slates," *Summ. Prog. Geol. Survey Great Britain for 1932* (1933), pp. 100–02.

[10] W. H. Benson, R. A. Keble, *et al.*, "Ordovician Graptolites of Northwest Nelson, N. Z." (second paper), *Trans. Royal Soc. New Zealand*, Vol. 65 (1936), p. 367.

McLISH FORMATION

The McLish formation crops out in many parts of the Arbuckle Mountains and at the north end of the Criner Hills. It consists of limestones, sandstones, and shales. In the eastern and central parts of the mountains and at the north end of the Criner Hills much of the limestone is dense with small flecks of calcite scattered through it so that it is called "Birdseye-like" limestone. As this type of limestone alternates in many places with sandstones and shales, and contains numerous worm borings, it is thought to be shallow-water in origin, and its distribution indicates that it was deposited in local basins. The sandstone at the base of the McLish is highly developed in the eastern and central parts of the Arbuckle Mountains. The thickness of 55 feet on U. S. Highway 77 decreases westward so that in a distance of 2 miles it is represented by only two thin stringers, and it is very thin in the western part of the mountains.

The term "Falls" was introduced temporarily because Ulrich contended that the rocks in the western part of the mountains in the same general stratigraphic position as those of the McLish of the eastern part had a fauna that was entirely different from that of the McLish. While the larger fossils of the McLish had not been found in the western part of the mountains, a concentrated zone of *Paleocystites tenuiradiatus* a short distance above the basal sand extends widespread through the mountains, and a thin *Ctenodonta* bed occurs 20 feet above this zone in the McLish in Sec. 29 and 32, T. 1 S., R. 4 E., 8 miles southeast of Sulphur. This *Ctenodonta* bed occurs with the same interval above the cystid zone on both sides of U. S. Highway 77, in Sec. 25, T. 2 S., R. 1 E. Recently a McLish sponge has been found at this same locality west of the highway. Also, a cephalopod, *Loxoceras moniliforme*, and a gastropod, *Maclurites magnus*, occurring in the McLish south of Sulphur in Secs. 11 and 12, T. 1 S., R. 3 E., have been found in the western part of the mountains, the former in Secs. 21, T. 2 S., R. 1 E., and Sec. 6, T. 2 S., R. 1 W., and the latter in Sec. 8, T. 2 S., R. 1 W. Furthermore, Loeblich found that 8 species of ostracodes characteristic of the McLish occur also in the western part of the mountains. These additional evidences indicate clearly that Falls should not be included in the Simpson group. Bridge[11] omitted Falls from the Ordovician table in the International Geological Congress Guidebook, but he retained it in earlier drafts of an Ordovician table being prepared by a committee of the National Research Council of which W. H. Twenhofel is chairman.

[11] Josiah Bridge, "Tentative Correlation of the Ordovician Formations," *Internat. Geol. Congress Guidebook 29* (1933), Pl. 2.

TULIP CREEK FORMATION

Because of a gradation of the Tulip Creek into the Bromide formation above, in the southern part of the Arbuckle Mountains, some consideration was given to uniting it with the Bromide formation. However, as it is a good distinctive formation in the western and southwestern part of the mountains, it is thought best to continue it as a regular formation. The Tulip Creek consists chiefly of shales and sandstones with minor amounts of limestone present. There are nearly 200 feet of shales and 150 feet of sandstones in Sec. 7, T. 2 S., R. 1 W., on West Spring Creek. While limestones increase eastward, shales dominate in Sec. 25, T. 2 S., R. 1 E., on the east side of U. S. Highway 77. In the new road cut southeast of Ada in Sec. 12, T. 1 N., R. 6 E., on Highway 48, 22 feet of Tulip Creek has been exposed where formerly it was thought to be wanting. A conodont, *Prinonodus aculeatus*, is its most characteristic fossil which occurs throughout shales, limestones, and in the basal sandstone. This conodont has been found in abundance in this new eastern road cut. A change is thus made in the distribution of the Tulip Creek extending it well into the eastern part of the mountains. The Tulip Creek was not recognized on the P. A. Norris ranch in Sec. 2, T. 1 N., R. 6 E., about 1½ miles northwest of this cut because at that locality that part of the Simpson section is covered with soil and grass.

BROMIDE FORMATION

The outcrops of the Bromide are more widespread than those of any other formation of the Simpson group. It occurs not only in many outcrops throughout the Arbuckle Mountains and at both ends of the Criner Hills in Secs. 16 and 35, T. 5 S., R. 1 E., but also it crops out at the lower edge of two of the Viola Hills at the northern edge of the Wichita Mountains in Sec. 14, T. 6 N., R. 16 W., and Sec. 20, T. 6 N., R. 15 W. It consists of limestones, shales and sandstones. Limestones occur at the top, shales alternate with limestones in the middle, and shales separate the sandstones at the base. It is thickest in Sec. 6, T. 2 S., R. 1 W., at the west end of the Arbuckle Mountains, where it is nearly 675 feet thick; it is 422 feet thick in the middle, in Sec. 22, T 2. S., R. 3 E.; the thickness decreases to 230 feet in Sec. 12, T. 1 N., R. 6 E., southeast of Ada, and to 128 feet in Sec. 31, T. 1 S., R. 8 E., at Bromide.

The Bromide is extremely fossiliferous. While some of the forms seem local in their development, it has many well marked distinctive fossil zones distributed through it in such a manner as to make possible the tracing of its various horizons through its numerous outcrops.

Bryozoans and brachiopods are especially abundant and some of them are diagnostic. Pelecypods and gastropods occur and ostracodes are very abundant. The graptolites in the upper part are very significant. *Amplexograptus maxwelli*, found 25 feet below the top of the Bromide, in Sec. 35, T. 5 S., R. 1 E., at the south end of the Criner Hills was found also near the top of the Bromide in the middle of the Arbuckle Mountains west of Nebo in Sec. 22, T. 2 S., R. 3 E. E. A. Frederickson[12] found this species in the Platteville of Wisconsin. This graptolite together with nearly a score of other invertebrates common to both

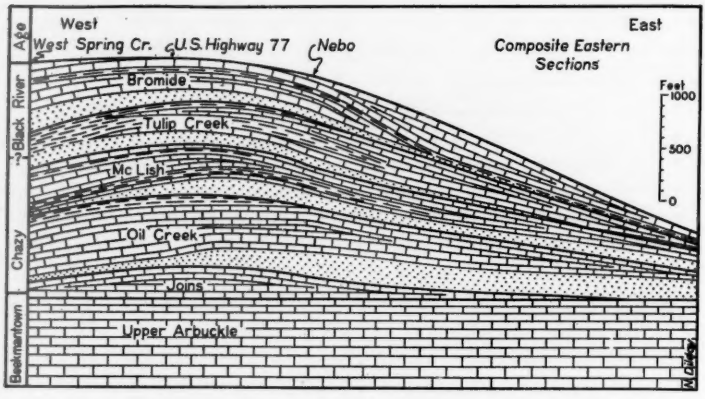

FIG. 1.—Graphic section of formations of Simpson group in Arbuckle Mountains of Oklahoma.

formations supplies evidence on which to correlate the Bromide and Platteville in these widely separated areas. Ekstrom[13] has recognized as this species a form from the upper *Didymograptus* shale of Sweden, but this zone seems much too low for the American species.

A very slender graptolite, *Dicellograptus mensurans*, occurs at the south end of the Criner Hills in the same zone with *Amplexograptus maxwelli*. This slender graptolite occurs also in the Normanskill shale of New York and thus suggests the correlation of the upper part of the Normanskill of New York with the upper part of the Bromide of Oklahoma. These two graptolites in the upper part of the Bromide formation occur only a short distance below a zone in the lower part of the Viola limestone in which many species of graptolites are found.

[12] C. E. Decker and E. A. Frederickson, "A New Graptolite Horizon in Wisconsin," *Jour. of Paleontology*, Vol. 15, p. 157 (1941).

[13] Gunnar Ekstrom, "Upper Didymograptus Shale in *Scania*," *Svereges Geologiska Undersokning*, Ser. C, No. 403, Arsbok 30 (1936), No. 10, p. 37. Stockholm (1937).

GRAPHIC SECTION

The graphic section (Fig. 1) differs from the one published in 1931 in the following respects. The Joins formation is extended farther east because it occurs in the section 8 miles southeast of Sulphur, but it is absent in the region east of that section. The thickness of the Oil Creek formation at the west end of the mountains is decreased by nearly 450 feet as a result of the reclassification of West Spring Creek section; and the Tulip Creek formation is extended to the eastern part of the mountains because of the exposure of 22 feet of it in the new cut southeast of Ada on Highway 48.

CORRELATION TABLE OF FORMATIONS OF SIMPSON GROUP

The correlation table is included especially to show changes noted since the 1931 table was published and to give information in regard to thickness in some newly measured sections. Section number 2 is given for comparison, while 3, 4, 6, and 9 are new measurements and 1, 5, 7, and 8 have been remeasured after more extended study and these four have been changed considerably.

DETAILED MEASURED SECTIONS

1. Revised Section of Simpson Group

Sec. 6, T. 2 S., R. 1 W., on West Spring Creek east of Pooleville. Dip, 23°–25° SW.

Zones	*Thickness (Feet)*		*Description*
	Zone	*Cumulative*	
			Bromide Formation, 674.5 feet thick
1	16.5	16.5	Thick gray limestones with *Receptaculites occidentalis*
2	30	46.5	Thin yellow and gray limestones, gastropods, *Tetranota obsoleta*
3	19.5	66	Thin limestones. *Rafinesquima minnesotensis, Liospira progne, Tetranota obsoleta*
4	45	111	Thin shaly limestones
5	19.5	130.5	Shaly, grass-covered. Large bryozoans and *Ischadites* cf. *iowensis*
6	17.5	148	Yellow and gray limestones with about one-sixth of zone more resistant at base. *Strophomenas* near top, large cephalopods near base. *Endoceras subannulatum*
7	45	193	Thin limestones, more resistant at base, *Cliftonia gouldi*. Equals zone 11 along U. S. Highway 77 and zone 3 at south end of Criner Hills
8	51.5	244.5	Mostly shaly slope, large bryozoans and *Ichadites* cf. *iowensis*
9	10	254.5	Resistant rough coarse yellow limestone
10	15	269.5	Shale interval
11	4.5	274	Coarse brown limestone
12	7.5	281.5	Mostly shale, some thin limestones at base. *Dalmanella fertilis, Dinorthis subquadrata, Herbertella bellarugosa, Orthis tricenaria*
13	18	299.5	Shale and a few thin limestones. *Prasopora simulatrix, Rafinesquina winchesterensis, Strophomena trentonensis*

Zones	Thickness (Feet) Zone	Cumulative	Description
14	10.5	310	Shales and thin limestones. *Monotrypa magna*
15	18	328	Shales and thin limestones, bryozoans and *Pleclambonites sericeus*
16	27	355	Shale, grass-covered
17	12.5	367.5	Brown fine-grained sandstone
18	10	377.5	Covered, shale or soft sand
19	25.5	403	Sandstone
20	42.5	445.5	Fissile green shales and a few thin sandstones
21	4	449.5	Resistant ledge of heavy sandstone
22	17.5	467	Fissile green and brown shales
23	1	468	Sandstone containing gastropods and cephalopods
24	15	483	Green and brown fissile shale
25	1	484	Sandstone and dark sandy limestone, brachiopods
26	16.5	500.5	Green and brown fissile shales
27	.5	501	Gray calcareous sandstones with bryozoans, gastropods, and cephalopods
28	18.5	519.5	Shales and thin sandstones, resistant sandstones at base
29	105	624.5	Grass-covered, shale or soft sand
30	50	674.5	White to brown fine sandstone
			TULIP CREEK FORMATION, 334.5 feet thick
31	137.5	812	Mostly green fissile shales with a few thin limestones and sandstones
32	12	824	Shales and thin limestones. *Valcourea strophomenoides*
33	35	859	Thin brown coarsely crystalline limestones, bryozoans, brachiopods, cystid plates
34	150	1,009	Mostly even-bedded white and yellow sandstone, case-hardened, some cross-bedded
			MCLISH FORMATION, 447.67 feet thick
35	50	1,059	Thin brown limestones and shales, small ramose bryozoans
36	25	1,084	Covered in flood plain of creek
37	3	1,087	Thin limestones and grayish green shale. *Dinorthis pectinella* abundant
38	13.5	1,100.5	Covered on flood plain
39	12.5	1,113	Coarse gray limestone, sandy at top
40	13.5	1,126.5	Green shales
41	82.5	1,209	Mostly thin limestones, some shaly
42	7.5	1,216.5	Mostly shale, some fine sandy limestones at base
43	42.5	1,259	Shale, grass-covered
44	15	1,274	Thin gray and brown limestones
45	7.5	1,281.5	Green fissile shale. Tyner?
46	2.5	1,284	Yellow limestones, cystid plates, and stems. *Palaeocystites* zone
47	17.5	1,301.5	Alternating shales and limestones, mostly shale, *Strophomenas*
48	125	1,426.5	Largely grass-covered
49	.17	1,426.67	Limestone filled with *Orthis acutiplicata*
50	30	1,456.67	Sandy limestone and some sandstone
			OIL CREEK FORMATION, 627.33 feet thick
51	15	1,471.67	Thin gray limestones
52	30	1,501.67	Sandy limestones and sandstones
53	16	1,517.67	Thin fine gray limestones, gastropods, and ostracodes
54	36	1,553.67	Brown and gray limestones, gastropods, and trilobites
55	27	1,580.67	Thin limestones on weathered slope. Numerous bryozoans
56	2	1,582.67	Thin brown limestones, bryozoans, gastropods, and cystids

Zones	Thickness (Feet) Zone	Thickness (Feet) Cumulative	Description
57	17.5	1,600.17	Thin brown limestones and some sandstones
58	37.5	1,637.67	Thin limestones and shales
59	1.33	1,639	Thin sandy limestones, numerous ostracodes
60	27.5	1,666.5	Soil-covered
61	12.5	1,679	Coarse yellowish brown sandstone, trilobites
62	75	1,754	Yellow and brown limestones, *Pliomerops nevadensis*, and ostracodes
63	65	1,819	Yellow and brown coarse limestones on slope, *Maclurites* sp.
64	100	1,919	Yellow and brown limestones, brachiopods, gastropods, ostracodes, small thin variety of *Receptaculites*
65	60	1,979	Thin and thick yellow limestones, brachiopods, ostracodes, and trilobites, *Clitambonites multicosta*
66	45	2,024	Thin limestones, brachiopods and ostracodes
67a	60	2,084	Thin limestones, pelecypod bed at base of zone
			JOINS FORMATION, 149.17 feet thick
67b	90	2,174	Thin beds of gray and yellow limestones
68	36	2,210	Thin limestones
69	23	2,233	Thin gray limestones, ostracodes
70	.17	2,233.17	Breccia containing gastropods. (Twenty-four feet above main gastropod bed in upper Arbuckle.) Total thickness, 2,233.17 feet

2. SECTION OF SIMPSON GROUP

North side of Falls Creek along road to Baptist Camp. NE. ¼, SE. ¼, Sec. 32, T. 1 S., R. 2 E. Dip, 88° SW., overturned; strike, N. 40° W.

Zones	Thickness (Feet) Zone	Thickness (Feet) Cumulative	Description
			BROMIDE FORMATION, 321.4 feet thick
1	5.2	5.2	Brownish gray limestone. Thin-bedded, few fossils. *R. minnesotensis*. One bed exceeds 2 feet in thickness
2	4.1	9.3	Marly zone with nodular limestones
3	9.7	19.	Heavy gray limestone
4	5.1	24.1	8-inch limestone at base. Remainder is alternating shale and limestone
5	4.2	28.3	Shale with a few thin limestones
6	2.6	30.9	Faulted wedge of coarse fossiliferous limestone
7	5.3	36.2	Green shale at base. Remainder is alternating thin limestone and shale with shale predominating. Top rests against small fault. Samples collected from top and base
8	6.1	42.3	Marly shale with a few thin limestones at base
9	6.2	48.5	Green shale
10	6.1	54.6	Covered with talus
11	8.9	63.5	Thin-bedded limestone with a few shale stringers
12	8.2	71.7	Heavy, bluish limestone at top. Beds 6–8 inches thick. Rest thin-bedded limestones, 1–2 inches thick, alternating with shale
13	9.1	80.8	Mostly shale with a few thin limestones, 2–3 inches thick
14	5.6	86.4	Mostly shale with a few thin limestones
15	8	94.4	Mostly shale with a few thin limestones
16	4.5	98.9	Thin-bedded limestone, with heavy bed at base
17	5	103.9	Shale with thin nodular limestones
18	5.6	109.5	Crystalline, gray limestone

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
19	8.1	117.6	Greenish shale with a few thin nodular limestones. Many bryozoans
20	12.1	129.7	Greenish brown shale, with a few thin nodular limestones. Many bryozoans
21	11.7	141.4	3 feet of limestone at top. Rest shale with interbedded nodular limestones, 1½–3 inches thick
22	8.8	150.2	Greenish shale with a few thin limestones
23	14.0	164.2	12-inch limestone at top. Rest alternating limestone and shale with thin limestones at base
24	3.8	168.0	Massive pinkish buff limestone
25	8	176.0	4 feet of green shale and thin limestones at the top. Rest in thin-bedded coarse crystalline limestone.
26	8.7	184.7	Coarse crystalline bryozoan limestone at base, with thin limestones and shales above
27	10.4	195.1	Thin green shale with a few nodular limestones. Many bryozoans
28	2.6	197.7	Fine crystalline gray limestone
29	9.6	207.3	Dominantly green shale, with some thin and nodular limestones. An upper 4-inch limestone and a lower 9-inch limestone
30	2.4	209.7	Massive limestones with a few bryozoans
31	4.3	214.0	Nodular limestone with thin buff shales
32	4.7	218.7	Sandstone, calcareous at top
33	2.7	221.4	Green to brown shale, some very fissile, with some thin sandy limestones. Shales predominate
34	8.3	229.7	Calcareous sandstone
35	12	241.7	Green shales with a few thin limestones. Many bryozoans, brachiopods, and cystid plates. One straight cephalopod. *Monotrypa* zone, 4 feet above base
36	7	248.7	Beds vertical, alternating thin, dark limestones and fissile green to greenish brown shale
37	5	253.7	Alternating thin sandstone and shale. Shale predominates in upper part, 8-inch shale at base
38	7.2	260.9	Yellow-brown sandstone with a few thin shales toward base. Numerous fucoids on basal beds
39	6.9	267.8	Predominantly green shale with a few thin sands in upper part
40	7.6	275.4	Yellow-brown sandstone, 3–5 inches thick, with some shale, much weathered
41	6.5	281.9	Greenish brown shales, with some thin sands in upper part
42	3.8	285.7	Yellow-brown sands with a few thin shales
43	11.2	296.9	Alternating sandstone and shale in upper part, in about equal amounts. In lower part shale predominates, with only a few thin sandstones
44	6	302.9	Massive bed of brown sandstone at base and in middle. Rest is alternating thin sands and shale
45	8.5	311.4	Talus-covered
46	4.8	316.2	8-inch sandstone at top, with abundant fucoids on base. Rest is green shale
47	5.2	321.4	1.4 feet brown sandstone at top. Lower half of zone is alternating thin shale and sand. 3–4 inches of sand beds in middle
			TULIP CREEK FORMATION, 313.1 feet thick
48	6.3	327.7	Green shale with a few thin sandstones in upper part
49	17.8	345.5	Alternating greenish brown shale and nodular limestone with 4-inch limestone 5 feet from base
50	15.6	361.1	Predominantly green fissile shale containing some thin brown sandstones

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
51	3.4	364.5	Blue-gray coarse crystalline limestones, brachiopods, bryozoans, and trilobite fragments
52	11.6	376.1	Green shale becoming brownish near the base
53	12	388.1	Beds overturned 15°. Alternating green shale and thin sandstones with sand predominating
54	19	407.1	Predominantly gray-green shale, one 14-inch sandstone a little above middle
55	1.6	408.7	Coarse crystalline yellow-brown limestone
56	8.8	417.5	Green shales with thin nodular limestones in middle
57	8.8	426.3	Thin green shale alternating with nodular limestone ½–1½ inches in thickness, a 3-inch limestone near base
58	12.3	438.6	2.3 feet of thin limestone beds, 3 inches thick at top, coarsely crystalline. Below is 4–5 feet of alternating thin shale and limestone. Rest of zone is thin limestone
59	3.6	442.2	*Top of "Wilcox."* Thin sandstones
60	25	467.2	18 inches of irregular red sandstone at base, rest is massive sandstone
61	42.6	509.8	Sandstone. Beds vary from 4 to 15 inches in thickness
62	3.5	513.3	Alternating thin sandstone and shale
63	6.5	519.8	3.8 feet of sandstone at top. Rest is alternating thin sandstones and shales
64	29.5	549.3	Massive sandstone
65	47.2	596.5	18 inches shaly zone at top. Rest is very massive sandstone
66	38	634.5	2 feet of thin sandstone and shale at top. Rest is massive sandstone
			McLish Formation, 164 feet exposed
67	26.4	660.9	3 feet of shale at top. Rest is light buff, crystalline limestone, sandy toward base. Thin blue limestone at top, many ostracodes
68	2	662.9	Irregular, faulted shale zone
69	12	674.9	Sandstone
70	13	687.9	Thin shale at top. Rest is light buff, crystalline limestone, sandy toward base. Thin blue limestone at top, many ostracodes
71	5	692.9	Thin shale at top. Base is heavy-bedded sandy limestone, many ostracodes and fucoids, 2.7 feet from top
72	8.8	701.7	Fucoidal, greenish brown sandy shale
73	8.8	710.5	Limestone with a few thin shales. 6.5 feet from top is bryozoan limestone
74	6.3	716.8	Alternating thin limestones and green shales, for 1 foot at base. Rest is green shale, with a few limestones, 4–6 inches thick
75	8.6	725.4	Fucoidal, calcareous sandstone, more calcareous toward base
76	13.6	739.0	Alternating thin nodular limestones and green shales
77	7.4	746.4	Thin shale and limestone at base, some sandy. At top are alternating nodular limestones and green shales
78	5	751.4	2 feet of green shale at top. Rest is alternating thin limestones and light green shales
79	14	765.4	Bright green shale. "Tyner"?
80	4.5	769.9	Alternating green shale and thin limestones
81	28.6	798.5	Massive, gray-blue limestone, weathering buff. Some beds sandy, coarse crystalline at base. Bifoliate bryozoans in basal beds. Rest of section is covered by flood plain of creek

3. Section of Part of Simpson Group

About a mile south of Sulphur on Highway 18, Sec. 11, T. 1 S., R. 3 E.*

Zones	Thickness (Feet) Zone	Thickness (Feet) Cumulative	Description
			Bromide Formation, 87.6 feet exposed
1	3.3	3.3	Yellow and gray shales and shaly limestones, bryozoans abundant
2	2.8	6.1	Gray coarse crystalline limestone, weathers yellow. Beds 4–10 inches thick
3	.9	7	Thin irregular limestone with red to green shale at base
4	1.3	8.3	Gray to buff thick bed of coarsely crystalline limestone
5	2	10.3	Irregular limestone and thin shale with 0.8 foot limestone at base
6	1.7	12.0	Reddish brown shale with 0.3 foot limestone bed in center
7	2.6	14.6	Irregular nodular limestones with partings of reddish shale
8	2.8	17.4	Red shale with green blotches in it. *Ischadites*, *Cliftonia gouldi*, *Monotrypa magna*, and other bryozoans
9	1.9	19.3	Coarsely crystalline fossiliferous limestone, beds 2–8 inches thick. Brachiopods at top
10	.7	20.	Red shale with some nodules of limestone
11	2	22.	Limestones at top 0.8 foot thick and at bottom 1 foot thick, thin red and blue shales between
12	1.2	23.2	Red shale at top with 0.6 foot limestone at base
13	11.	34.2	Buff dense limestones
14	4.5	38.7	Dense, thin limestones with shale partings
15	2.3	41.0	Calcareous sandstone beds 6–14 inches thick
16	1	42.0	Platy banded fissile shale, reddish with lighter bands
17	3	45.	Two beds of buff limestone, each 1.5 feet thick
18	3	48.0	Limestone, 0.8 foot thick at top, alternating thin limestone and shales below, many bryozoans
19	3	51.0	Thick bed of sandy limestone with large sand grains included
20	5	56.0	Buff thin dense limestones
21	2.9	58.9	Calcareous sandstone, coarse at base
22	1.4	60.3	Thin lenses of limestone separated by gray shale partings ½–1 inch thick. Bryozoans on limestone surfaces. *Rhinidictid* beds
23	1.5	61.8	Light gray coarsely crystalline limestones
24	11.8	73.6	Lenticular limestones and shale, shale predominating
25	3.7	77.3	Brownish red shale, many bryozoans
26	10.3	87.6	Calcareous sandstone to base of road cut

Higher beds of Bromide occur on slopes at east above which contact with Viola is covered. South along highway, McLish and Oil Creek formations occur in outcrops not favorable for measuring.

Several faults in section were taken into account in measuring section.

Supplementary Note.—Because of lack of time when appropriations were cut off from the Oklahoma Geological Survey in 1931, some details were omitted from the geologic map of the Arbuckle Mountains. Small outcrops of Viola limestone and of the Bromide formation south of Sulphur were not included. Also there was failure to note the presence of asphalt in the intraformational and basal sandstones of the McLish in sections 11 and 14, T. 1S., R. 3E. The very large asphalt deposits southwest of Sulphur seem to be chiefly in the McLish formation.

* Outcrop not shown on Geologic map of Arbuckle Mountains.

4. SECTION OF SIMPSON GROUP

Sixteen miles southeast of Ada on State Highway 48, Sec. 12, T. 1 N., R. 6 E.

Zones	Thickness (Feet)* Zone	Thickness (Feet)* Cumulative	Description
			BROMIDE FORMATION, 230.6 feet thick
1	.1	.1	Clay bed, bryozoans
2	.5	.6	Coarse crystalline limestone at top, finer below
3	1.1	1.7	Fine "Birdseye-like" limestone
4	.7	2.4	Thin limestone and shale
5	.35	2.75	Fine, "Birdseye-like" limestone
6	1.25	4.	Thin limestone and shale (0.2 foot shale at top)
7	1.25	5.25	6 inches limestone at top, rest irregular limestone
8	1.25	6.5	Limestone bed, fairly fine texture
9	1.25	7.75	0.35 foot limestone at top, rest shales
10	1.5	9.25	Two beds of limestone with 0.1 foot shale between
11	4.85	14.1	Thin limestone beds (0.1–0.2 foot), thin shale films between
12	1.1	15.2	Limestone bed, fossiliferous
13	1.55	16.75	Thin limestone (0.05–.15 foot), shale 0.15 foot at base
14	2.15	18.9	0.6 foot limestone at top, 0.2 foot shale, 1 foot limestone, rest shales at base
15	7.5	26.4	Heavy limestone beds, 0.5 foot thick–2 feet thick. Dip, 19° NE.
16	5	31.4	Thin limestone interbedded with sandy shale at base
17	6	37.4	Limestone 0.35–0.5 foot thick, sandy toward base
18	5.8	43.2	Limestone 0.5–0.75 foot thick
19	1.55	44.75	Limestone bed
20	1.45	46.2	Thin limestones, shaly at base
21	3.2	49.4	Two limestone beds, crystalline
22	12.5	61.9	Thin irregular limestones, some thin shales
23	1.7	63.6	Limestones
24	3.75	67.35	Shales and thin limestones
25	1.55	68.9	Crystalline limestone. Dip, 25° NE.
26	3.3	72.2	Shales and thin limestones
27	25	97.2	Covered in valley
28	5	102.2	Cross-bedded sandy limestone
29	4.65	106.85	Crystalline limestone
30	2	108.85	Crystalline limestone, shaly at base
31	3.25	112.1	Coarse crystalline limestone
32	4.5	116.6	Crystalline limestones, thinner at base
33	3	119.6	Gray limestones
34	13.4	133.	Shales and thin limestones, 0.1 foot bed of limestone in middle
35	3.75	136.75	Nodular limestones and shales
36	3.25	140.	Bryozoan shales
37	1.4	141.4	Sandy limestone, 0.5 foot shale at base
38	4.35	145.75	Sandy limestone, finely crystalline, shale partings
39	4.65	150.4	Thin sandy limestones, 0.25 foot clay bed at top
40	3.6	154.	Indurated yellow sandstone, calcareous
41	4.4	158.4	Blue to gray sandstone. Calcareous
42	1	159.4	Thin-bedded blue sandy limestone. Dip has changed from about 20° NE. to low anticline at last 5 or 6 zones
43	6	165.4	Sandstone. Faulted zone—especially last 40 feet. Dip, 12°–15° NE.
44	12	177.4	Covered in valley
45	5.5	182.9	Thin yellow sandstone and sandy shale
46	2	184.9	Argillaceous, bluish gray shale with chalky lenses

* Measurements perpendicular to bedding planes. Dip, N. 30°.

Zones	Thickness (Feet) Zone	Cumulative	Description
47	2.7	187.6	Crystalline limestone, thin shale partings
48	8	195.6	Shales, gray top, green base. Also limestone nodules
49	10	205.6	Coarse crystalline gray limestone, coarse sandstone at base
50	1.15	206.75	Grayish brown shale, 0.2 foot limestone near top
51	3.85	210.6	Coarse crystalline, bluish gray limestone
52	8	218.6	Sandy limestone, partly cross-bedded
53	.75	219.35	Shale, with thin crystalline limestone
54	3.85	223.2	Fine gray calcareous limestone, more calcareous near base
55	.4	223.6	Dark shale
56	7	230.6	Irregular calcareous sandstone and loose sand
			TULIP CREEK FORMATION, 22.15 feet thick
57	.6	231.2	Dark green shale
58	3.55	234.75	Thin greenish gray sandy limestone, shaly at base, embraced by small fold
59	8	242.75	Coarse crystalline sandy limestone. *Prionodus aculeatus*
60	4	246.75	Limestone, shales and sandstone. *Prionodus aculeatus*
61	6	252.75	Red-brown sandstone exposed west of road
			McLISH FORMATION, 75 feet exposed
62	12	264.75	Limestones and shales
63	4.5	269.25	Fine "Birdseye-like" limestone
64	.65	269.9	Shale, some thin limestone in it
65	10	279.9	"Birdseye-like" limestone
66	5	284.9	Green shale
67	2.5	287.4	Thin limestones, 0.6 foot bed at base
68	.8	288.2	Shale, chalky content
69	3.7	291.9	"Birdseye-like" limestone
70	.45	292.35	Shale, light green
71	2.85	295.2	"Birdseye-like" limestone
72	1.55	296.75	Sandy limestone 0.2 foot shale at top
73	3	299.75	Green shale, chalky at base
74	28	327.75	"Birdseye-like" limestone. Continuing southwest, plain is grass-covered about 700 feet with some limestones exposed with evidence of complex faulting to top of Arbuckle limestone. In ravine about 40 rods east of south end of this section about 280 feet of "Birdseye-like" limestone is well exposed

5. SECTION OF SIMPSON GROUP, NORTH END OF CRINER HILLS

Beginning 600 feet south of north line of Sec. 15, T. 5 S., R. 1 E., and 145 feet east of west line, thence southwesterly across Sec. 16. Strike, N. 30° W.; dip, 70-80° NE. Above contact, dense brownish limestone of basal Viola limestone grades rapidly upward into thinner cherty beds

Zones	Thickness (Feet)* Zone	Cumulative	Description
			BROMIDE FORMATION, 363.3 feet thick
1	5.1	5.1	Gray, finely crystalline massive beds of limestone. (On U. S. Highway 77, heavy beds are more than twice this thick.) *Ischadites* and *Rafinesquina minnesotensis*
2	8.1	13.2	Beds thin, 2–4 inches, gray to buff in color and very dense
3	2.9	16.1	Fine-grained buff limestone in beds 2–6 inches thick

* Calculated from tape measurements and dip.

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
4	21	37.1	Gray to yellowish limestones with 6-inch fossiliferous bed at top
5	64.7	101.8	Covered with soil except for two thin limestone beds at top
6	41.7	143.5	Largely coarsely crystalline resistant limestones in beds 2–10 inches thick
7	64	207.5	Yellowish brown crystalline limestones with about 6 feet of argillaceous shales above the 18- to 20-inch limestone beds, *Glyptocystites logani*, *Dinorthis pectinella*, *Herbertella bellarugosa*, *Orthis triceneria*, *Plectambonites sericeus*
8	14.5	222.	Soil-covered
9	24.2	246.2	Yellowish sandstone in thin beds with some interbedded shale
10	117.1	363.3	Soil-covered, with 7- to 8-inch coarsely crystalline limestone slumped at top of zone
			TULIP CREEK FORMATION, 485.5 feet thick
11	74.2	437.5	Coarsely crystalline brown limestones in beds 4–6 inches thick at base, upper part covered with soil
12	117.1	554.6	Zone covered with soil too deeply to yield information by digging hole several feet deep
13	26.3	580.9	Brown coarsely crystalline limestones with greenish gray shale partings, numerous small brachiopods and branching bryozoans
14	94	674.9	Covered with soil
15	70.3	745.2	Three subzones of thin-bedded limestones separated by wider covered areas. Brachiopods and bryozoans abundant
16	34.5	779.7	Thin-bedded limestones 2–4 inches thick, coarsely crystalline; a lenticular 4-inch cherty zone near base
17	15.4	795.1	Covered with sandy soil. Excavation shows small fragments of sandstone
18	23.2	818.3	Massive beds of gray crystalline limestone
19	30.5	848.8	Coarsely gray limestone with two covered sandy zones, one 4 feet and the other 5 feet thick. A few oölitic limestones in this zone
			MCLISH FORMATION, 437.7 feet thick
20	68.2	917.	Gray to light brown limestones. Many trilobite fragments in bed near top. Oölites 8 feet from top. Brachiopods 20 feet below top. Second oölite about 30 feet below upper one. Limestone beds vary from 3 to 18 or 20 inches in thickness
21	22	939	Mostly coarsely crystalline limestones with zone of thin sandstones at base. Lower 2½ feet consists of coarsely crystalline limestones with many fucoids at base, *Paleocystites tenuiradiatus* present
22	88.8	1,027.8	Covered with soil
23	94	1,121.8	Upper 11 feet thin-bedded "Birdseye-like" limestone, massive beds of this limestone through rest of zone, very large ostracodes and some gastropods in upper parts of zone. Dip, 70°
24	20.7	1,142.5	Two thin limestones exposed in zone mostly covered with sandy soil
25	70.5	1,213.	Coarsely crystalline gray limestone, mostly thin, ½–18 inches above base. Zone contains ostracodes, *Orthoceras*, and trilobite fragments
26	73.5	1,286.5	Mostly covered with soil some of which is sandy

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
			OIL CREEK FORMATION, 558.8 feet thick
27	98.7	1,385.2	Zone mostly covered. A few coarsely crystalline yellowish brown limestones exposed. Numerous bryozoans on surface. *Pliomerops nevadaenses* and *Leperditellas*
28	366.1	1,751.3	Much of zone covered with soil. In middle of zone yellowish brown limestones are exposed in ditch along east-west fence. *Pliomerops*, large gastropods, bryozoans, pelecypods, and *Clitambonites multicosta*
29	94	1,845.3	Largely covered with soil, 1½ feet breccia at base, many ostracodes and *Orthoceras*
			JOINS FORMATION, 198.8 feet thick
30	13	1,858.3	Thin limestones with many ostracodes. Heavier beds at base contain *Didymograptus artus-D. bifidus* zone
31	75.8	1,934.1	Mostly covered with soil except two thin limestones at base
32	110.	2,044.1	Thin limestones, mostly soil covered to 8-inch breccia conglomerate at base
			Total thickness of Simpson group 2,044.1 feet

6. SECTION OF SIMPSON GROUP

Rock Crossing, Criner Hills. Sec. 35, T. 5 S., R. 1 E., Dip, 55° SW.; strike, N. 25° W. (107 feet of Viola exposed above Bromide.)

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
			BROMIDE FORMATION, 315.01 feet thick
1	.3	.3	Clay bed with bog iron at top. Weathered surface
2	6.1	6.4	Gray limestone beds 3–8 inches thick. *Rafinesquina minnesotensis, Dinorthis subquadrata, Herbertella bellarugosa, Recaptaculites, Ischadites*
3	41	47.40	Thin limestones with shale partings, 7 feet shaly in upper part. *Plectambonites sericeus, Cliftonia gouldi, Dinorthis subquadrata*
4	108.24	155.64	Thin-bedded argillaceous limestones. *Ampyx McGeheei. Diplograptus maxwelli, Dicellograptus mensurans*
5	41	196.64	Buff limestones in beds mostly 2–3 inches thick but some up to 12 and 18 inches. Shale layers at base. *Orthoceras* zone. Many bryozoans near base
6	34.44	231.08	Largely green shales and thin limestones. Lower *Ischadites* bed. Upper cystid zone. *Glyptocystites logani.* Brachiopods, bryozoans abundant. *Monotrypa magna*
7	27.06	258.14	Green shales and thin limestones. Bryozoans very abundant. Dip, 70°. *Orthis tricenaria* zone
8	23.97	282.11	5 feet sandy limestone at top. 8 feet thick beds of sandstone. About 10 feet thick sandstones and sandy shales. Dip high, 70°–80°
9	6.58	288.69	Green argillaceous shales, a few thin limestones
10	5.64	294.33	Thin, lenticular sandstones with thin shales between
11	20.68	315.01	Chiefly green shales with some thin sandstones and sandy limestones. Dip, about 80°

Zones	Thickness (Feet)		Description
	Zone	Cumulative	
			TULIP CREEK FORMATION, 88.69 feet exposed
12	30.08	345.09	Sandy limestones and shales
13	18.61	363.70	Zone largely covered, some sandy limestones at base
14	8	371.70	Uncovered by recent erosion. Light green shale
15	2	373.70	Yellowish and slightly green argillaceous shale
16	20	393.70	Fine gray slightly sandy shale
17	10	403.70	Gray and yellow shale containing 8-inch yellow limestone bed
			Rest of section covered by Pennsylvanian beds

SUMMARY

The Simpson group consists of a remarkable series of alternating limestones, sandstones, and shales. The thickness increases westward so that it is nearly three times as thick at the west end of the mountains as it is at the east end. In general in the two lower and the middle formations, limestones and shales increase toward the west and sandstones toward the east. In the two upper formations sandstones hold their importance into the western end of the mountains and the sandstones of the Bromide decrease in the eastern part. The new highway cut southeast of Ada has exposed a thin section of Tulip Creek where formerly it was thought to be absent. The reclassification of the section at the west end of the mountains on West Spring Creek has given a more normal thickness to all five formations, especially by the reduction of the thickness of the Oil Creek formation.

Recent studies have supplied more evidence to justify the position taken in regard to the former classification into five formations, particularly with reference to the unity and distinctiveness of the Bromide formation, and in discarding "Falls" as a formation in the western part of the mountains.

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DEVONIAN SUBSURFACE STRATA IN WESTERN KENTUCKY[1]

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ABSTRACT

An attempt has been made to correlate the subsurface Devonian and Silurian strata in the western Kentucky basin with equivalent beds in the generally distant outcrops. Samples from about forty wells were studied, zoned on the basis of general lithology and insoluble residues, and a tentative correlation of these zones with the outcrop material suggested. The formations recognized at the surface in southern Illinois can be traced into the subsurface in western Kentucky.

The absence of the Decatur and upper Brownsport of the Tennessee Silurian from the sections high on the flank of the Cincinnati arch, and their presence on the west side of the basin indicates some post-middle Silurian and pre-Devonian uplift and erosion. The Kentucky Lower and lower Middle Devonian strata may represent the seaward facies of the Arkansas and Texas novaculites as thickening toward the southwest suggests that the source of the thick cherts and dolomites was in that direction.

Post-Hamilton warping of the basin, perhaps as a result of relative east-west uplift occasioned by movement of the Nashville dome, served to cut off the southern end of the syncline. This resulted in the preservation of a complete section of Lower and Middle Devonian in the deepest part, and the stripping of the Hamilton and most of the Onondaga from the east, south, and west sides. All or nearly all of the Devonian sediments were removed from the region high on the Cincinnati arch side of the basin, from Hardin County south to Barren County, before deposition of the Chattanooga shale.

INTRODUCTION

PURPOSE

The purpose of this investigation is to correlate the subsurface Devonian strata in the western Kentucky basin with the equivalent beds in the generally distant outcrops. So far as possible the work has been carried on through study of well samples, on the basis of both general lithology and insoluble residues. This paper covers the progress to date on this study, and includes subsurface correlation by zones supplemented by tentative correlations of these zones with outcrop material. As new information becomes available through future drilling the suggested correlations may be substantiated or altered.

LOCATION OF AREA

The region covered in greatest detail by this study is that part of Kentucky west of the Devonian outcrop on the western flank of the

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[2] The writer wishes to thank the Kentucky State Department of Mines and Minerals, especially D. J. Jones, who suggested the problem and who was responsible for the collection of most of the well samples, and Miss Lena Palmer who was of inestimable aid in the preparation of the samples for study. Such subsurface studies are only possible through the coöperation of the operators, drillers, and geologists working in this area, and the writer wishes to express appreciation to them for their assistance. Special thanks are due Carey Croneis for assistance in the collection of outcrop samples in Missouri, and for his criticism of and helpful advice in the preparation of the manuscript.

Cincinnati arch, and east of the Tennessee River. Inasmuch as the limits of the basin are not determined by political boundaries, it has been necessary to obtain much information from neighboring states, especially southeastern Missouri, southwestern Illinois, southern Indiana, and western Tennessee.

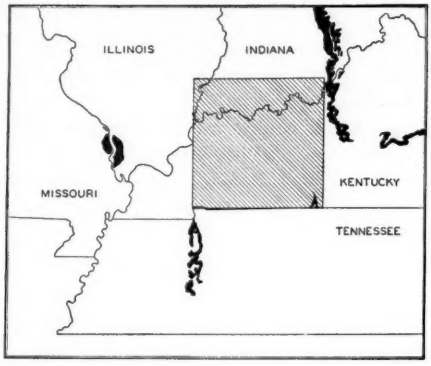


FIG. 1.—Map showing area included in this study and its relation to areas of Devonian outcrop.

STRATIGRAPHY OF DEVONIAN OUTCROP

LOWER DEVONIAN

The Lower Devonian does not crop out in Kentucky, but is represented in western Tennessee, southwestern Illinois, and southeastern Missouri.

TENNESSEE

The section as exposed in the valley of the Tennessee River is described by Dunbar (11)[3] as follows.

HELDERBERGIAN

Rockhouse shale.—This formation was named by Dunbar (10: p. 736) and described as a southward-thickening wedge inserted between the Ross limestone above and the Silurian Decatur limestone below. The Rockhouse is

> A glade-forming, calcareous shale of greenish gray color, interbedded with occasional thin bands of light gray, crystalline limestone. Toward the base of the shale, the bands of the limestone become thicker and closer set, so that the formation appears to grade into the underlying Decatur (11: p. 38).

The maximum thickness of the formation is 26 feet at its type exposure

[3] Figures in parentheses refer to bibliography at end of article.

at Rockhouse, a hunters' clubhouse on Horse Creek, 5 miles northwest of Lowryville. The most characteristic fossils are *Anoplotheca concava, Bilobites bilobus, Nucleospira concentrica, Rhipidomella oblata, Scyphocrinus* (*Camarocrinus*) *saffordi, Edriocrinus pocilliformis,* and *Pleurodictyum trifoliatum.*

Olive Hill formation.—This formation was named and described by Dunbar (10: p. 738) from an exposure in a bluff on Indian Creek at Olive Hill, Hardin County. It consists of three distinct lithologic units. In ascending order, these are the Ross limestone, the Bear Branch, and the Flat Gap members.

The Ross limestone member was defined by Foerste (14) and named from exposures on the Ross farm, near Sulphur Springs, Hardin County. It is impure, dark gray, siliceous and cherty limestone in thin layers, and is extremely hard, compact and cliff-forming. "The silica is so finely disseminated that it may not appear as chert even where the rocks analyze over 20 per cent SiO_2" (11: p. 45). At the south the member contains thin bands of bluish chert at irregular intervals. The fresh rock is bluish gray, hard and dense, but with exposure it turns brown, the lime is leached, and a residue of insoluble silica remains as a soft porous shaly sandstone. The Ross limestone has a maximum thickness of 60 feet and is the most persistent member of the Olive Hill formation. The most conspicuous fossils are *Scyphocrinus* (*Camarocrinus*) root bulbs.

The Bear Branch member was named by Dunbar (10: p. 738) from an exposure on Bear Branch, about 2 miles southeast of Olive Hill, Hardin County, where it forms a bluff showing 20 feet of low-grade ore resembling the Clinton type. It is impure limestone, coarse-grained, with oölitic hematite in the lower part, and thickly stratified, rather pure, cross-bedded limestone with streaks of oölitic iron ore in the upper part. The member, whose maximum thickness is 45 feet, is but sparingly fossiliferous, the most characteristic species being *Anastrophia verneuili, Schellwienella woolworthana, Rhipidomella oblata, Spirifer cyclopterus, S. perlamellosus,* and *Favosites helderbergiae.* Toward the south the Bear Branch member grades into the Pyburn limestone, the lower part of which is thin-bedded, dirty, impure, and cherty, with sporadic bands of chert 2–10 inches thick. The upper part is more heavy-bedded than the lower and lithologically it closely resembles the Ross limestone.

The Flat Gap member is a heavy-bedded, coarsely crystalline or granular limestone, white or pinkish in color, and sparingly fossiliferous. The most characteristic fossils are *Rhipidomella oblata, Spirifer cyclopterus, Delthyris perlamellosa,* and *Dalmanites pleuroptyx.*

Birdsong formation.—Dunbar (10: p. 741) described the Birdsong formation and named it from its typical exposures along the valley of Birdsong Creek in Benton County. He states (11: p. 55) that Foerste tentatively regarded this formation as a correlative of the Pyburn, but that his own studies have indicated that this correlation is erroneous.

> The Birdsong formation begins with a few feet (8–10) of heavy-bedded, rather pure, coarsely crystalline limestone. Above this it passes into interbedded bluish shale and thin bands of crystalline limestone and then into softer, calcareous, blue shale, constituting the upper half to three-fourths of the formation. Harder calcareous laminae and thin bands or lentils of limestone occur throughout the shale. When fresh the latter is partly indurated by its large percentage of calcium carbonate, but it weathers into bluish clay and a rubble of small limy fragments forming barren hillside slopes or "glades," . . . (11: p. 55).

The Birdsong is 35–65 feet thick and goes under cover toward the north without any marked decrease in thickness. It thins toward the south, however, and in some sections is entirely absent. Erosion has reduced its thickness toward the east where in places there remain only about 10 feet of the lower calcareous part overlain by the Hardin sandstone.

The Birdsong is highly fossiliferous with brachiopods dominant except in one zone which is replete with bryozoans. The most characteristic fossils are *Dalmanites pleuroptyx, D. retusus, Phacops logani, Anastrophia verneuili, Anoplotheca concava, Bilobites varicus, Cyrtina dalmani, Platyorthis planoconvexa, Gypidula coeymanensis, Leptostrophia becki, Nucleospira ventricosa, Orthostrophia strophomenoides, Spirifer cyclopterus, S. macropleurus, S. perlamellosus, Edriocrinus pocilliformis,* and *Scyphocrinus* (*Camarocrinus*) *mutabilis.*

Decaturville chert.—This formation was defined by Dunbar (10: p. 744) and named from typical exposures near Decaturville, Decatur County. It is only about 6 feet thick, but it is widely distributed. The Decaturville consists of yellowish to gray or slate-colored chert disconformably overlying the Birdsong. The upper few inches are very porous and extremely fossiliferous; the lower part is lighter-colored and thinner-bedded. The fossils are preserved as natural molds and casts or pseudomorphs, and are remarkably large. The most characteristic forms are *Anoplotheca concava, Platyorthis planoconvexa, Spirifer perlamellosus, Eatonia medialis, E. singularis, Rhipidomella oblata, Stropheodonta* (*Leptostrophia*) *becki,* and *Pleurodictyum lenticulare.*

ORISKANIAN

Quall limestone.—This is the lower formation of the upper Oriskany in western Tennessee. It was named by Dunbar (10: p. 746) from its outcrop on the farm of Jim Quall in the valley of Dry Creek, a small stream entering the Tennessee River near Walnut Grove, Hardin County. Its total thickness does not exceed 10 feet. Dunbar (11: p. 69) states that

> Where freshly exposed, the limestone is light gray in color, rather fine-grained, and disposed in layers from 18 to 24 inches thick. It appears slightly magnesian, and highly siliceous. Upon deep weathering it breaks down into a very porous rotten white and yellow chert and yellow clay, in which fossils abound as free pseudomorphs in silica.

The Quall limestone is present only locally, but its southward extension is greater than that of the overlying Harriman novaculite. Such fossils as *Spirifer arenosus*, *S. murchisoni*, and a large *Striatopora* indicate its Oriskany age.

Harriman novaculite.—This formation was named by Dunbar (10: p. 747) from exposures on Harriman Creek, Decatur County. It overlies the Quall and is in turn overlain by the lithologically similar Camden chert from which it is distinguished only by its fauna.

> The Harriman chert or novaculite is nearly white on fresh exposure, but weathers to shades of yellow and buff. It is disposed in layers varying from a few inches to over a foot in thickness, and is very hard and brittle. Where exposed to weathering, it is thoroughly fractured into small angular fragments and in this condition so very closely resembles the Camden chert that only the fossils can be relied on to distinguish the two formations (11: p. 71).

The novaculite is 30–55 feet thick, the thickest sections being at the north. The Harriman disconformably laps over older formations and in places rests directly on middle Silurian strata. The most characteristic fossils are *Leptostrophia magniventra*, *Chenostrophia complanata*, *Plethorhyncha* cf. *barrandei*, *Rensselaeria ovoides*, *Spirifer murchisoni*, *S. arenosus*, *Meristella lata*, *Anoplotheca dichotoma*, and *Platyceras gebhardi*.

Dunbar's correlation of the Devonian in western Tennessee with the Devonian of the New York section is shown on the following chart.

ILLINOIS

The Devonian strata, exposed only in western Union and southwestern Jackson counties in Illinois, have been described by Bassett (1) and Savage (28, 29, 30).

HELDERBERGIAN

The Helderberg is represented by the Bailey limestone, described by Ulrich (35) in 1904 from an exposure at (the former) Bailey's Landing on the Mississippi River, Perry County, Missouri, a short distance above Red Rock Landing. The Bailey is best exposed along

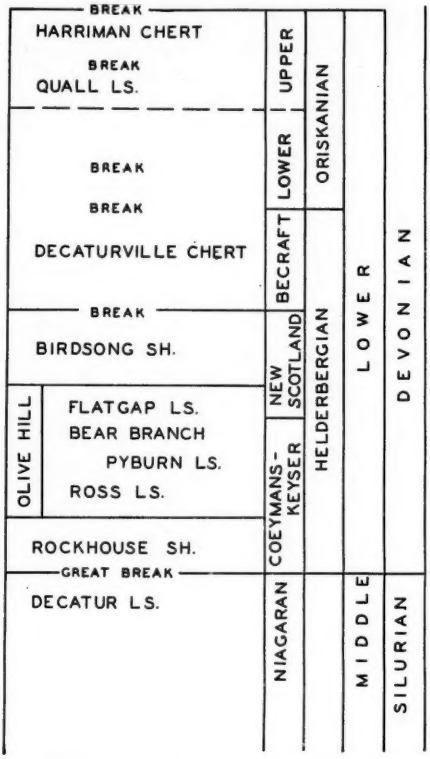


FIG. 2.—Generalized section of Lower Devonian in western Tennessee.

the Mississippi River below Grand Tower in Jackson County, Illinois. The limestone is thin-bedded, gray, earthy, or dolomitic, containing chert nodules commonly transformed to tripoli on exposure. In places it is 200 feet thick. Fossils are rare but those present indicate Helderbergian New Scotland affinities; a few exposures contain numerous *Scyphocrinus* (*Camarocrinus*) bulbs.

ORISKANIAN

Rocks of Oriskany age in Illinois consist of a lower thick-bedded chert formation, the Grassy Knob, which is 150 or more feet thick. This passes upward with gradual transition into a coarsely crystalline limestone, the Little Saline (Backbone), which is about 200 feet thick.

Grassy Knob chert.—This formation was described by Savage (30) from an outcrop on the west side of Grassy Knob, Jackson County, Illinois. It is a very rough-surfaced, hackly, thick-bedded, gray to reddish brown chert in layers 12–48 inches thick. The layers become thinner toward the top where they change to rather even-bedded, whitish, iron-stained layers 4–8 inches thick (1). Fossils are rare and are mainly *Anoplotheca flabellites*, *Orthotetes pandora* and *Spirifer murchisoni*. There is no apparent stratigraphic break between this formation and the underlying Bailey.

Little Saline limestone.[4]—This limestone is known only in the northwestern corner of Union County and the southwestern corner of Jackson County. Bassett has estimated its thickness at 230 feet. It consists of light gray, more or less crystalline, crinoidal limestone with much bedded chert in thin irregular bands. It contains several thick layers of coarsely crystalline white limestone similar to the Little Saline of southeastern Missouri. The chert is more porous than that of either the Grassy Knob below or the Clear Creek above, and contains molds of crinoid stems and bryozoan fragments.

The fossils are large and abundant only in the lower massive layers; they become smaller in size upward. The following forms suggest the Oriskanian age of this formation: *Beachia ovalis*, *B. suessansa*, *Leptostrophia magnifica*, *Plethorhynchia barrandei*, *Rensselaeria marylandica*, and *Spirifer arenosus*.

A marked erosional disconformity separates the Little Saline limestone from the overlying Clear Creek chert. The limestone thins to disappearance south and east; and where the Grassy Knob and Clear Creek cherts are thus brought in contact they are practically indistinguishable due to the almost total lack of fossils.

MISSOURI

The Devonian of southeastern Missouri is exposed in the Little Saline faulted area chiefly in Ste. Genevieve County. Weller and St.

[4] Savage first described and named this formation the Backbone limestone from its exposure near the south end of Devil's Backbone Ridge, a short distance north of Grand Tower, Jackson County. *Amer. Jour. Sci.*, 4th Ser., Vol. 49 (1920), pp. 169–78. Later, however, he recognized its equivalency to the Little Saline, as described by Weller for the Missouri section, and he replaced his earlier name with the Little Saline limestone. *Amer. Jour. Sci.*, 5th Ser., Vol. 10 (1925), pp. 139–44.

Clair (38: p. 131) assign a thickness of about 640 feet to the Devonian strata which in this area all belong to the lower and middle divisions of the system.

HELDERBERGIAN

Bailey formation.—This formation, named by Ulrich (35: p. 110) is very much like the Bailey already described for Illinois, particularly the lower half of the 200 feet usually assigned to the Bailey in Missouri. Above this is 5–10 feet of

> light gray, very granular crystalline limestone, and the overlying upper half of the formation consists mainly of chert that is rarely well exposed but produces conspicuous talus deposits on the hillsides. The chert is light colored and breaks into angular fragments. Much of it is dense but some is porous and contains the impressions of fossils (37: p. 128).

The upper part of the formation is more fossiliferous than the Bailey of Illinois, and the fossils in the main are silicified.

J. M. Weller (37: p. 128) suggests that the upper part of the Bailey might be equivalent to part at least of the Grassy Knob chert of Illinois. The lower part of the Bailey is less fossiliferous and is characterized by *Leptaena rhomboidalis*, pygidia of large *Dalmanites*, and many bulbous stem bases (*Camarocrinus*) of the crinoid *Scyphocrinus*.

Microscopic examination of hand specimens[5] and of insoluble residues show the lower Bailey limestone to be white to light tan-gray, very coarsely crystalline, crinoidal and cherty with most of the chert as partial replacement of crinoid ossicles. The 5–10 feet of limestone in the middle of the formation is very fossiliferous, coarsely crystalline, granular, and gray with much green and some pink calcite. The upper portion of the Bailey is similar to the lower in its coarsely crystalline character but it contains much chert, some of which is dull white and some white mottled translucent and dull.

ORISKANIAN

Little Saline limestone.—The Bailey is succeeded in Ste. Genevieve County, Missouri, probably disconformably, by the Little Saline limestone which is about 100 feet thick. It was first described and named by Dake (9: p. 88), the name having been taken from an unpublished manuscript by Stuart Weller. Weller and St. Clair describe it as

> a very pure, thickly bedded, more or less coarsely crystalline limestone, nearly white in color or with a slight pinkish tint, and is filled with fossils in its lower half. One bed towards the top is decidedly crinoidal, with great numbers of fragments of crinoid stems upon the weathered surfaces. At some iso-

[5] Outcrop samples of the Devonian were collected from Ste. Genevieve County, Missouri, under the direction of Carey Croneis.

lated outcrops, where fossils are scarce, it is difficult to distinguish some portions of this limestone from certain beds of the Kimmswick limestone, but usually sufficient fossil evidence can be secured to differentiate the two formations. In the upper half of the formation there are two beds of dense, hard, close-textured, nearly white limestone, with great numbers of a Bryozoan resembling those forms which have been described as *Lichenalia*. The first of these beds, ten feet in thickness, lies immediately above the more coarsely crystalline, highly fossiliferous beds, the other being at the extreme summit of the formation, about eight feet thick. Between these two *Lichenalia* beds the rock is coarsely crystalline, similar to that in the lower half of the formation, but much less fossiliferous (38: pp. 137–38).

The formation is apparently entirely free from chert, and some beds have the characteristics of a good marble.

Microscopic examination of the Little Saline reveals it to be very coarsely crystalline and crinoidal with green calcite here and there and streaks of more finely crystalline pink limestone. A few large rounded and frosted quartz grains appear in the insoluble residues.

The most abundant fossils are *Spirifer murchisoni*, *S. arenosus*, *Rensselaeria ovoides*, *Plethorhyncha barrandei*, *Diaphorostoma ventricosum*, *Platyceras gebhardi*, *Anoplia nucleolata*, *Anoplotheca flabellites*, *Beachia suessansa*, *Chonostrophia complanata*, *Eatonia peculiaris*, *Leptostrophia magnifica*, *L. magniventra*, *Megalanteris ovalis*, *Metaplasia pyxidata*, and *Rhipidomella muscula*. This fauna, according to Butts (4: p. 401), is typical for the Oriskany fauna of New York, whereas Weller and St. Clair (38: p. 141) consider it a transition fauna between the Lower Devonian Oriskany and the Middle Devonian Onondaga faunas.

CORRELATION

HELDERBERGIAN

There is no equivalent to the Rockhouse shale of Tennessee in the sections of Illinois and Missouri. Dunbar (11: p. 43) regards its position as being close to the Siluro-Devonian boundary line because of the predominance in the fauna of Devonian species, accompanied by a number of Silurian forms and primitive expressions of such species as *Pleurodictyum trifoliatum* and *Rhipidomella preoblata*. Due to the thick overlying Helderbergian section he considers this fauna to be about the same age as the Keyser formation of Maryland, but he suggests that there was no direct communication between the Mississippian embayment and the Appalachian trough.

The Olive Hill formation is very closely related to the succeeding Birdsong which is more exactly the equivalent of the New Scotland. Since the Olive Hill is considerably older than the Birdsong in its faunal development Dunbar considers it the correlative of the upper

Coeymans. *Scyphocrinus* (*Camarocrinus*) bases, which are so characteristic of the Tennessee Helderberg, are also common in the Bailey of Missouri and Illinois, and in the Haragon shale of Oklahoma. The Decaturville chert is correlated by Dunbar (11: p. 68) with the lower part of the Becraft of New York on the basis of the considerable dis-

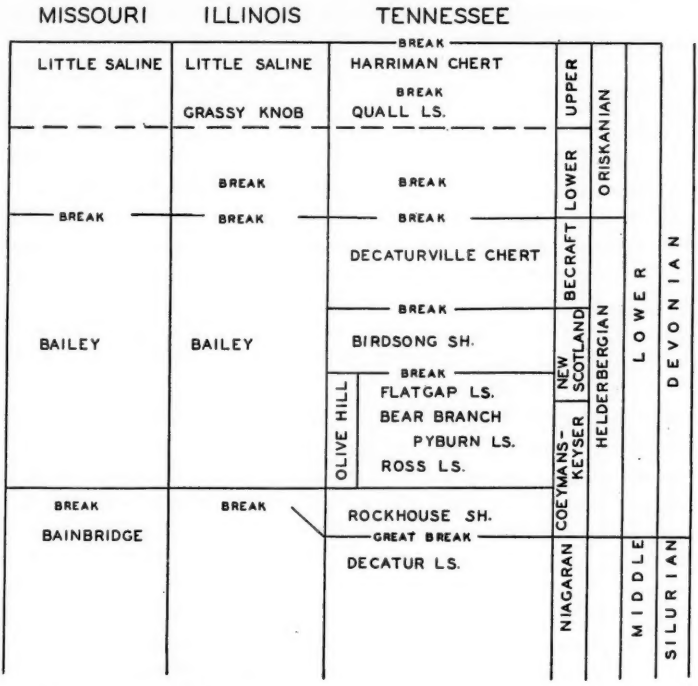


FIG. 3.—Generalized sections of Lower Devonian in western Tennessee, southwestern Illinois and southeastern Missouri.

conformity at its base, in spite of the lack of a definite Becraft facies in the fauna. This would make the chert equivalent to the upper Bailey of Illinois.

ORISKANIAN

Savage (30) suggests that the Quall limestone of Tennessee, Dunbar's lower upper Oriskany, is part of the Grassy Knob chert, and that the upper, more fossiliferous Harriman chert, which contains a large Oriskany fauna, probably represents a part of the Little Saline limestone of Missouri and Illinois.

MIDDLE DEVONIAN

TENNESSEE

The Middle Devonian exposed in western Tennessee consists of two formations, the Camden chert and the Pegram limestone, the former beds resulting from "an earlier invasion from the southwest, the latter representing a brief incursion of the Onondagan coral fauna which apparently spread southward into Tennessee from the Kentucky-Ohio basin where it was so well developed at the Falls of the Ohio" (11: p. 77).

ONONDAGAN

Camden chert.—The Camden was named by Safford and Schuchert (26) from an exposure at Camden, Benton County. Dunbar (10) restricted the name to the upper 200 feet of the beds to which it had formerly been applied, and subdivided the lower part into the Harriman, Quall, and Decaturville. He described the Camden as follows.

> It is a white to buff-yellow, brittle novaculite. Although flinty hard and very resistant to decomposition, the ultimate effect of weathering is to reduce the rock to finely powdered silica mixed with more or less clay, the latter being an insoluble impurity in the novaculite (11: p. 79).

The novaculite breaks with an irregular fracture into sharp-edged fragments, and natural outcrops appear only as a loose rubble of rough, angular pieces of chert. The bedding is rarely regular for more than a few yards, and the strata display considerable crumpling in spite of the fact that the overlying and underlying beds show no deformation. These typical characters are maintained in every exposed section except that at the "whirl" on Buffalo River, where there is a series of interbedded limestones and cherts directly overlain by the Pegram limestone. At this locality both the fauna and lithology are different from those at other exposures, and in all other sections the Camden is disconformably overlain by much later strata of late Devonian or even Cretaceous age. Dunbar (11: pp. 80–81) suggests that this is younger Camden which was protected by the Pegram while its correlatives were being eroded during later Middle Devonian time. The absence of many of the typical Camden fossils and the presence of *Spirifer macrothyris*, an Onondagan species, supports his belief that the beds on Buffalo River should be regarded as strata transitional between the true Camden and the Pegram limestone.

Dunbar gives a maximum exposed thickness of 164 feet for the Camden on Cypress Creek. Where the Camden rests on the Harriman novaculite a disconformable contact is not discernible although it is inferred from the faunal break. In many places, however, the Camden

rests on older Devonian, the underlying strata in some places being as old as the Bryozoan layer of the Birdsong. The characteristic fossils are *Anoplia nucleata, Chonostrophia reversa, Pentagonia unisulcata, Leptocoelia flabellites, Chonetes hudsonicus camdenensis, Spirifer hemicyclus, S. worthenanus, Eodevonaria arcuata, Amphigenia curta,* and *Atrypa reticularis.* The following species, however, are more characteristic of this formation as it is exposed in the Buffalo River area: *Rhipidomella* cf. *penelope, Leptaena rhomboidalis, Stropeodonta cf. blainvillei, S.* cf. *hemispherica, Schuchertella pandora, Chonostrophia reversa, Eatonia peculiaris, Oriskania condoni, Amphigenia curta, Leptocoelia flabellites, Spirifer macrothyris, S. hemiculus,* and *Meristella lentiformis.*

Pegram limestone.—Foerste (13: pp. 400–25) described and named this formation from exposures at Pegram, Cheatham County. Later Pohl (24) in an abstract divided the Pegram into the Sellersburg limestone above and the Jeffersonville below, and suggested discarding the name Pegram. The name Pegram is being used in this report as Pohl's complete evidence for this change is not available. It is a rather pure, heavy-bedded, light gray limestone which reaches its maximum thickness of 12 feet in the Pegram exposures. As mentioned above, in the Buffalo River area it overlies Camden, but at Pegram it rests on Middle Silurian limestones. The characteristic fossils are *Stropheodonta demissa, S. perplana, Rhipidomella penelope, Nucleospira concinna,* the diagnostic Onondaga blastoid *Nucleocrinus verneuilli,* and the corals *Heliophyllum, Blothrophyllum, Cystiphyllum, Cyathophyllum,* and *Cladopora,* which indicate its equivalency to the Jeffersonville.

Foerste (13: p. 425) described another Pegram section in the Harpeth River region where the Silurian Louisville limestone is overlain by the limestone thickening to the west. The upper 6–12 inches are earthy, and contain small black pebbles similar to those found in the top of the Devonian in southern Indiana and Kentucky. This darker layer contains *Camarotoechia carolina, Tropidoleptus carinatus* and *Spirifer pennatus,* and represents the Sellersburg equivalent.

HAMILTON

The Hamilton group is represented in western Tennessee only by the few feet of Sellersburg which Pohl and Foerste (13: p. 425) identified in the top of the Pegram limestone.

ILLINOIS

ONONDAGAN

The Middle Devonian is represented in Illinois by both the Onon-

daga and the Hamilton groups. At Hicks Dome in Hardin County, southeastern Illinois, the Devonian is exposed near the crest of an anticlinal structure. The base of the Onondaga is not readily observed but its presence is demonstrated by the appearance of such fossils as *Amphigenia curta*, *Spirifer duodenarius*, *S. varicosus*, and *Nucleocrinus verneuili*. The Onondaga is overlain by an undetermined thickness of Hamilton limestone and chert containing *Chonetes coronatus*, *Meristella haskinsi*, *Spirifer audaculus*, and *S. iowensis*.

In southwestern Illinois, Alexander, Jackson, and Union counties, the Onondaga is reported to include three divisions, in ascending order: Clear Creek chert, Dutch Creek sandstone, and Grand Tower limestone. The Hamilton is represented by the Misenheimer shale and the Lingle limestone.

ONONDAGAN

Clear Creek chert.—Worthen (41: pp. 126–29) as early as 1866 gave this name to a series of fossiliferous, siliceous limestones exposed on Clear Creek, Union County, Illinois, which he stated were Helderbergian and Oriskanian in age. Dunbar (11: pp. 68–69, 89, 91) later demonstrated the correlation of the Clear Creek with the Camden chert of Tennessee, which he referred to the Onondaga. Savage (20: pp. 169–78) and Pohl (25: pp. 54–63) suggested an equivalency to the Esopus and Schoharie grit of New York, but later Savage (29) agreed with Dunbar in its Onondaga age. The United States Geological Survey (36) classifies the Clear Creek limestone as of Oriskany and Onondaga age.

The Clear Creek, as described by Bassett (1), is commonly thin-bedded, slightly iron-stained, gray chert. In places the upper part is made up of alternating crystalline limestones and chert layers, commonly novaculitic, whereas the lower part is commonly made up of layers of chert 10–12 inches thick. In the northwest outcrop area this formation rests disconformably on the Little Saline limestone, but at the southwest where the Little Saline disappears, the chert is hard to distinguish from the underlying Grassy Knob. Savage (29) has estimated the thickness of the Clear Creek chert to exceed 300 feet, but J. M. Weller (37: p. 129) suggests that it may be considerably more. Weller also states that "this formation is believed to overlie the Backbone (Little Saline) limestone conformably."

Silicified fossils and molds of fossils are common, especially in the upper part. The most characteristic forms demonstrating Onondagan age are *Chonostrophia reversa*, *Spirifer* cf. *divaricatus*, *S. duodendarius*, and *Dalmanites calypso*.

Dutch Creek sandstone.—Savage described and named this formation from exposures on Dutch Creek in southwestern Union County, Illinois. It is a reworked sand of the St. Peter type, commonly stained brown with iron oxide. The beds are massive and hard, and vary in thickness from a few inches to 30 feet. The Dutch Creek contains numerous molds of fossils, the most characteristic forms being *Pleurodictyam problematicum*, several species of *Zaphrentis*, *Leptostrophia perplana*, *Rhipidomella* cf. *penelope*, *Amphigenia curta*, *Spirifer duodendarius*, *S. macrothyris*, and a species of *Odontocephalus*. The sandstone rests conformably on the Clear Creek below and grades into the Grand Tower above.

Grand Tower limestone.—Keyes in 1894 (17: pp. 30, 42) first gave this name to the Onondaga and Oriskany limestones of southeastern Missouri. In 1910 Savage (27) limited the name Grand Tower to those limestones representing the western equivalent of the New York Onondaga limestone. These strata have a thickness of approximately 125 feet at Backbone Ridge, north of Grand Tower in Jackson County, Illinois. They are rather pure granular to sub-crystalline limestones, light to dark gray in color, and thickly stratified, locally with some chert. The most significant fossils for correlation are *Odontocephalus aegeria*, *Phacops cristata*, *Proetus crassimarginatus*, *Platyceras dumosum*, *Conocardium cuneus*, *Paracyclas elliptica*, *Meristella nasuta*, *Nucleospira concinna*, *Pentamerella arata*, *Spirifer acuminatus*, *S. duodenarius*, *S. macrothyris*, *S. raricostus*, *S. varicosus*.

MARCELLUS AND HAMILTON

Misenheimer shale.—Savage (28: pp. 169–78) described the Misenheimer and named it from exposures in Misenheimer Creek, Union County, Illinois.

> It consists of a maximum thickness of about 30 feet of very silty and massively bedded shale which weathers to a drab color and locally resembles the Springville shale of lower Mississippian age (37: p. 129).

The shale in places overlaps the Grand Tower, the Dutch Creek sandstone, and the Clear Creek chert; in such places the basal part is a greatly disturbed dark shale containing numerous shells of *Leiorhynchus limitare*. Savage (29) states that the shale corresponds both in stratigraphic position and faunal content with the Marcellus shale of New York. Weller (37: p. 129) agrees in general with this statement but points out also that the Misenheimer in part grades laterally northward into the Lingle limestone of Hamilton age.

Lingle limestone.—Savage (28: pp. 171–76) described and named this formation from exposures along a branch of Lingle Creek, Union

County, Illinois, where it conformably overlies the Misenheimer shale. The Lingle consists of dark gray to nearly black, thinly stratified limestone, which is in places very impure and silty. The thickness of the Lingle limestone plus the Misenheimer shale is 88–100 feet. That it is Hamilton in age is suggested by the following fossils: *Microcyclus discus, Chonetes pusillus, C. coronatus, Tropidoleptus carinatus, Vitulina pustulosa, Athyris spiriferoides, Spirifer audaculus, S. fornacula, S. granulosus, S. pennatus.*

MISSOURI

Both the Onondaga and the Hamilton groups are represented in the Middle Devonian of southeastern Missouri, where the Onondaga, although consisting of three formations in southwestern Illinois, is represented solely by the Grand Tower limestone. The Marcellus and Hamilton equivalents are the Beauvais sandstone below and the St. Laurent limestone above.

ONONDAGAN

Grand Tower limestone.—The formation is limestone throughout although somewhat variable in lithologic character. Weller and St. Clair (38: p. 143) give the following typical section, which is exposed along the east bank of Little Saline Creek, Ste. Genevieve County.

		Feet
11.	Limestone, a white finely crystalline marble; as exposed on the surface more or less interruptedly, the beds are thin and some of them include numerous grains of quartz sand scattered more or less regularly through the limestone matrix	15
10.	Talus covered interval	40
9.	Limestone, fine-grained, granular, hard and tough, bluish upon freshly fractured surfaces, becoming brown with weathering. Rather thinly bedded. Fossils abundant in some beds, the brachiopod genus *Schizophoria* the most common form	55
8.	Limestone, in thin even beds, nearly pure crystalline, white to buff in color. Fossils very scarce	85
7.	Limestone, light colored, mostly nearly white, in rather heavy beds, the texture variable, from granular to dense. Filled with fossil corals in great variety	25
6.	Limestone, coarsely crystalline, very pure and nearly white, similar to the Little Saline limestone in texture and appearance. Weathered surface rough, with numerous fragmental crinoid stems. The basal part contains corals in abundance	25
5.	Limestone, dense, hard, compact, and brittle, with numerous irregular chert concretions. No fossils observed	12

It will be observed that the Grand Tower, which is 250 feet thick in Ste. Genevieve County, is sandy in its *upper* part, whereas the section at the type locality in Illinois, where it is only 125 feet thick, contains sandy *lower* beds in the zone of gradation into the underlying Dutch Creek sandstone.

A microlithologic study of the Grand Tower shows it to be some-

what arenaceous throughout but with an increase of coarse sand upward toward the Beauvais and an increase of silty sand toward the base. Descriptions of hand specimens are as follows.

6. Limestone (near base of Beauvais sandstone), brown, arenaceous with much sand evenly distributed through it. Sand grains are large, rounded and frosted, and show no secondary enlargement. They are well sorted as to size with no fine silty sand such as occurs below
5. Limestone, white, with numerous large rounded and frosted sand grains scattered through it. Limestone shows a little superficial pink stain
4. Limestone, not so coarsely crystalline as above and with more pink color. There are only a few large rounded and frosted sand grains, but some very fine sand appears in residue
3. Limestone, slightly dolomitic, dark brown, finely crystalline to dense, with a little fine rounded sand enclosed
2. Limestone, very coarsely crystalline and pink. Residue shows some very fine sand with rare large rounded and frosted grains
1. Limestone, more finely crystalline and pink than above, with much more fine sand and still showing rare large rounded and frosted grains

MARCELLUS AND HAMILTON

Beauvais sandstone.—Dake (9: p. 88) described this formation, taking the name from an unpublished manuscript by Stuart Weller. The Beauvais is exposed only in the Little Saline fault area of Ste. Genevieve County, where it attains a thickness of less than 50 feet. It consists of massive beds of reworked St. Peter type; it is very coarse grained and white, or stained with iron oxide. Fossils are very poorly preserved, but the rare *Newberryi claypolei* has long been recognized. In 1931 Croneis and Hoffman (7) collected and listed a considerable fauna from the Beauvais sandstone, and demonstrated its similarity in stratigraphic position and faunal content to the Marcellus of New York. It is conformably transitional between the underlying Grand Tower and the overlying St. Laurent limestone.

Microlithologic examination shows that the sand content of the Grand Tower increases until it grades insensibly into the overlying Beauvais, and that the Beauvais becomes more calcareous toward the top. Some layers resemble the upper layers of the Grand Tower except that the sand grains are not so evenly distributed in the Beauvais and the sand itself is very poorly sorted as to grain size. There is a dolomite layer at the top, pale pink to yellow in color, finely crystalline with an uneven distribution of large sand grains, and flaggy on outcrop. The sand in the middle part of the section ranges from fine to very coarse and practically all grains show secondary crystal growth, the crystals being almost complete in many instances.

St. Laurent limestone.—This formation was first described by Dake (9: pp. 88, 175) and named the St. Lorenz. Wilson (39: p. 51) later referred to this limestone as the St. Laurent, having taken the name from an unpublished manuscript by Stuart Weller. The type

exposure is along St. Laurent Creek about 3 miles south of St. Marys, Ste. Genevieve County. J. M. Weller described the St. Laurent as follows.

> This formation which includes about 275 feet of strata at its type locality, is extremely variable in lithology and includes various types of limestone that are mainly thin-bedded, fine-grained, and gray to bluish in color. Several layers in various parts of the St. Laurent are more or less sandy and there are several beds of pure sandstone composed of grains probably reworked from the St. Peter or some older formation. Limestone conglomerate also occurs and some chert is present although this is commonly found in the residuum derived from the formation and is seldom observed in place. Fossils are rare or absent in most of the St. Laurent strata. It is improbable that any important break in sedimentation separated this formation from the underlying Beauvais sandstone (37: p. 129).

The most characteristic fossils are *Pterinea flabella, Chonetes coronatus, Eunella lincklaeni, Cyrtina hamiltonensis, Spirifer audaculus, S. macronatus,* and *Cystiphyllum americanum.*

Microlithologic examination of the St. Laurent shows that the limestone in general is more finely crystalline and dense than the Grand Tower. Some layers are light gray, almost lithographic limestone and some are arenaceous with poorly sorted grains of rounded and frosted quartz. There are a few beds of white sandstone, with the grains showing a wide size range and a previously rounded and frosted surface texture. The sandstone is closely cemented by secondary crystal growth, which feature is better exhibited than in the Beauvais sandstone below. Near the base there is a conglomeratic layer of limestone containing very finely crystalline quartz, some large rounded and frosted grains, small round pebbles of brown limestone similar to some of the Grand Tower and pebbles of very finely crystalline light gray limestone, lighter in color than the matrix.

SOUTHERN INDIANA

Both the Onondaga and Hamilton are represented in southern Indiana, the Onondaga by the Pendleton sandstone and the Jeffersonville limestone, with the Geneva in the northern part of the area, and the Hamilton by the Sellersburg limestone.

Pendleton sandstone.—Cox (6: p. 62) described and named this sandstone from its exposures at Pendleton, Madison County, Indiana. He stated that according to James Hall it contained Schoharie fossils and assigned it to the Corniferous. Kindle (19: pp. 558–61) described the Pendleton as being the stratigraphic equivalent of the Jeffersonville limestone, and Cumings (8: p. 464) called it Schoharie. Logan (21) described it as being locally conglomeratic and a true basal sand-

stone; he doubted that it was the western representative of the Schoharie grit, but placed it below the Jeffersonville in his tables. It consists of 15 feet of heavy-bedded, soft, white sand, the upper part of which is fossiliferous. The characteristic fossils include *Reticularia fimbriata, Martinia subumbona, Pentamerella arata, Atrypa reticularis, Tentaculites dexitheca, Bellerophon curvilineatus, Conocardium trigonale, Proetus curvimarginatus, P. latimarginatus, Cyrtoceras eugenium, Zaphrentis giganteum, Favosites limitaris,* and casts of *Pleurotomaria.*

Geneva limestone.—The Geneva was first described and named by Collett (5: pp. 63, 81–82) from exposures at Geneva, Shelby County, Indiana. Kindle (19: p. 537) suggested that this limestone replaced the Sellersburg and Jeffersonville to the north, but later he (20: p. 313) decided that the fauna indicated its age as either Schoharie or Onondaga, probably Schoharie. Cumings (8: p. 466) stated that the actual relationships of the Geneva and Jeffersonville-Sellersburg formations have not been satisfactorily determined, and that the Geneva might be a lithologic facies of one or both of these formations, or more likely a distinct formation older than the Jeffersonville.

In a recent paper D. G. Sutton and A. H. Sutton conclude that

> The Geneva is a northward lithologic facies of the Jeffersonville formation of Onondaga age as shown by the Onondaga faunules of the Jeffersonville, which continue into the Geneva at the same horizons and by the lateral transition from the dolomitic Geneva limestone to the purer Jeffersonville limestone. This gradation begins farthest south in the lowest beds and reaches the progressively higher beds toward the north, which makes it appear upon casual investigation that the Jeffersonville thins toward the north, the thinning being accompanied by a corresponding thickening of the Geneva (34: p. 331).

They also suggest that by priority the term "Geneva" should be applied to all Indiana rocks of Onondaga age.

The Geneva first appears in the section 10 or 15 miles north of the Falls-of-the-Ohio, where sections which include both the Jeffersonville and the Niagaran begin to show between them thin beds of rather soft, dark buff to brownish, fine-grained, saccharoidal magnesian limestone, locally cherty. This Geneva type limestone thickens northward as the Jeffersonville limestone thins, and reaches the maximum known thickness of 62 feet on Bear Creek in the NW. $\frac{1}{4}$, SW. $\frac{1}{4}$ of Sec. 30, T. 8 N., R. 8 E.

> The presence at the top of the section here of thin beds with *Spirifer acuminatus* and *Stropheodonta hemispherica* indicates that not much if any of the formation is missing. These brachiopods and their associated forms are found wherever the upper part of the Geneva or Jeffersonville is exposed (34: p. 327).

SOUTHERN INDIANA AND KENTUCKY

Inasmuch as the Devonian outcrop in southern Indiana and north-central Kentucky is more or less continuous, and is characterized by the typical expression of the Jeffersonville and Sellersburg formations, this district is treated as a single area in the following descriptions.

The Devonian rocks exposed in Kentucky consist only of the Onondaga and Hamilton limestones. The principal outcrop of these limestones is in a very narrow strip between the Silurian and Ordovician limestones and shales which underlie the Bluegrass region on the crest of the Jessamine dome of the Cincinnati arch, and the encircling outcrop of the Chattanooga black shale. Small patches of Devonian strata are exposed on the Cincinnati anticline south of the main area, along Green and Cumberland rivers and some of their tributaries (Fig. 1). The most complete section of the limestones is to be seen at Louisville, Jefferson County, from which they thin southward by the omission of the lower beds. The pattern of the outcrop curves eastward to Lebanon, Marion County. The eastern and western areas of Devonian rocks are separated for a short distance, at least in the outcrop, across the crest of the Cincinnati anticline between Lebanon and Crab Orchard, eastern Lincoln County.

ONONDAGAN

Jeffersonville limestone.—Kindle (18: pp. 8, 23, 110) described this formation and named it from the city of Jeffersonville, Clark County, Indiana, near the famous coral beds at the Falls-of-the-Ohio where it is so well represented. He defined it as the "lowest formation of the Devonian as developed at the Falls-of-the-Ohio lying between the Sellersburg beds and the *Catenipora* (*Halysites*) beds of the Niagara." These ancient coral reefs attracted attention in the early part of the nineteenth century, and were mentioned by many of the early workers. The name "Corniferous" limestone was applied to all of the Devonian limestones of this area by Eaton (12: pp. 61–71, 198) and the term is still used by oil drillers for undifferentiated limestone strata below the Chattanooga black shale.

The surface distribution of the Jeffersonville limestone is confined to the north-central part of Jefferson County, Kentucky, in the bed and on the banks of the Ohio River, and in Indiana just northwest of Jeffersonville to within ½ mile of the mouth of Silver Creek where it dips below water level. There is no complete section known exposing both top and bottom of the Jeffersonville limestone so the entire thickness is not definitely known. Butts (2: p. 104) gives the following section compiled from exposures near the Whirlpool, one mile west of Jeffersonville.

		Feet
5.	Limestone, massive, rather coarse-grained, light-gray, a little black chert locally. Whitish and shelly on weathering. Exfoliates diagonally to the bedding. *Spirifer acuminatus* about in top. *Stropheodonta heimispherica* abundant and conspicuous, Bryozoa abundant, includes bryozoan and *Nucleocrinus* subzones of authors. *Spirifer acuminatus* zone	9
4.	Limestone, siliceous, cherty, bluish-gray, fine-grained, very hard. *Spirifer gregarius*, very abundant. *Favosites hemisphericus*, *Turbo shumardi*, etc. *Spirifer gregarius* zone	2
3.	Limestone, 6 inches to 1 foot layers, medium, coarse-grained, light pinkish, bluish, or brownish gray. In places largely made up of *Stomatopora*	7
2.	Limestone, medium thick-bedded, very coarse crystalline, brownish in part. Crowded with corals. Coral layer	7
	Certainly Jeffersonville	25
1.	Limestone, covered with water, not identified	3

The sequence of lithologic and faunal characters described above is the same wherever the Jeffersonville approaches its normal thickness. The basal coral zone is persistent and wherever the contact with the Silurian is exposed the strata immediately above the *Halysites catenularia* zone are crowded with corals. Likewise the *Spirifer gregarius* zone and the *Spirifer acuminatus* or *Stropheodonta hemispherica* zones persist wherever the Jeffersonville has been observed. The abundance of the fossils of this limestone, especially of the fossil corals, has contributed largely to the fame of the Falls-of-the-Ohio among paleontologists the world over.

HAMILTON

Sellersburg formation.—Kindle (18: pp. 8, 20, 110) named this formation from exposures near Sellersburg, Indiana, and described it as a "fine-grained calcareous sandstone, with a thin bed of limestone at the top, overlain by the New Albany shale and underlain by the Jeffersonville limestone." It is composed of the Beechwood member above and the Silver Creek below. Sutton (34: p. 326) proposes the name "Speeds member" to designate 18 inches of shaly limestone exposed below the Silver Creek at Speeds quarry, near Sellersburg. This thin bed is included in the Sellersburg because of the occurrence in it of *Spirifer audaculus*.

Siebenthal (33: p. 345) named the Silver Creek Hydraulic limestone from exposures on Silver Creek, Clark County, Indiana. He described it as a homogeneous fine-grained, bluish to drab, argillaceous, magnesian limestone, up to 16 feet thick, overlain by the Sellersburg. Butts (2: pp. 118–20) divided the Sellersburg as described by Kindle into the Silver Creek limestone member below and the Beechwood limestone member above. This division is generally accepted. The Silver Creek is most typically exposed along the stream from which it was named. So far as it is known to crop out in Ken-

tucky, the Silver Creek is limited to a relatively small area along the river bank north of Louisville and extending eastward as a thin layer to the lower part of Beargrass Creek in Jefferson County.

According to Butts (2: p. 119) the composition of the Silver Creek ranges approximately 50–60 per cent calcium carbonate, 16–35 per cent magnesian carbonate, 10–25 per cent silica, and 2–5 per cent alumina. Much of the silica is in the form of chert. The Silver Creek is moderately fossiliferous, the most characteristic and abundant forms being brachiopods and pelecypods.

The Beechwood limestone member was named by Butts (2: pp. 118–20) from exposures in a stream "at a point a few rods north of the Shelbyville turnpike one-half mile south of Beechwood, and one and one-half miles east of St. Mathews." He described it as a coarse, crinoidal limestone, 2–8 feet thick, the "Encrinal" limestone of early workers, the Sellersburg of Siebenthal, and the top member of the Sellersburg of Kindle and Butts. It is rather heavily stratified, the lower part being light gray in tone and fairly coarsely crystalline in texture, whereas the upper part is finer-grained and darker in color. The abundance of crinoid stem plates gives it a coarsely crystalline appearance. The Beechwood is separated from the Silver Creek below by irregular bedding planes above which are numerous black phosphate nodules containing small linguloid shells, fragments of bryozoans, crinoid joints and some ostracodes. The contact with the overlying New Albany is sharply demarcated, and commonly the upper few inches of limestone are altered to pyrite. The Beechwood limestone member can be readily recognized in its typical lithologic and faunal characters at only a few localities south of northern Bullitt County. For example, the Beechwood facies can be recognized below the Casey limestone at the type locality in Casey County. Butts (3) described a section which includes the Beechwood on Barren River in Barren County as follows.

	Feet
Chattanooga shale	
1. Shale, black, thin calcareous sandstone layers in the lower 10 feet, the associated shale carrying the characteristic Genesee shale fossils *Schizobolus truncatus* and *Lingula spatulata*	43
Devonian limestone	
2. Sandy limestone or calcareous sandstone, chocolate brown, medium textured. Cemented to the underlying limestone. Hamilton age?	1*
3. Limestone, gray, coarsely crystalline, highly fossiliferous, crinoid stem plates abundant, also corals, bryozoans, and brachiopods. Layers about 1 foot thick. Some of the crinoid columns like those of the Beechwood ("Encrinal") limestone of the Louisville region, of Hamilton age. "Cap rock" of oil operators	5
4. Limestone, bluish-gray, fine-grained, compact, rather distinct in the sec-	

* Probably the Duffin layer which Savage refers to the base of the black shale.

tion at the mouth of Little Glover Creek..... 2

5. Limestone, massive, weathers pitted and cavernous, variable in color and texture, sparingly fossiliferous at mouth of Little Glover Creek, coarsely crystalline, very light gray, and full of small sandy lenticles weathering to sandstone. At mouth of Dry Creek, bluish gray, fine-grained. Oil bearing stratum of the Devonian; probably Onondaga (Corniferous) age..... 7–9

Miller (22: pp. 220–42) correlates the thin Devonian limestone of Allen County with the Beechwood by means of a species of *Dolatocrinus*. Shaw and Mather (32: p. 47) collected fossils from exposures in Allen County and sent them to Ulrich for identification. His discussion is as follows.

The collection comprises four small pieces of nearly pure bluish-gray, mainly fine-grained limestone. Two of the pieces contain only columnals of a thick-stemmed crinoid, possibly *Dolatocrinus* or *Megistocrinus;* the third has a weathered coral suggesting a young *Heliophyllum halli*, a very common Middle Devonian fossil; the fourth retains an exfoliated pedicle valve of some terebratuloid brachiopod, possibly *Eunella lincklaeni*. Of these only the coral is at all diagnostic (32: p. 47).

The most characteristic fossils of the Sellersburg are *Spirifer hobbsi, Athyris fultonensis, Stropheodonta demissa, Clinopistha antiqua, Chonetes acutiradiatus, Gomphoceras turbiniforme, Productella subaculeata cataracta, Heliophyllum juvene, Rhipidomella vanuxemi, Paracyclas lirata, Tropidoleptus carinatus, Modiomorpha concentrica, Pentagonia unisulcata, Spirifer fornacula, Ambocoelia umbonata, Chonetes yandellianus,* and *Spirifer oweni.*

Casey limestone.—The name Casey limestone was proposed by Savage (31: pp. 12, 143–44) for a cherty limestone containing Hamilton fossils which overlies the Beechwood member of the Sellersburg, and is below the Duffin layer in the base of the black shale. It is typically exposed near Kidd's Store, Casey County, Kentucky. The upper part of the Casey is thick-bedded, gray, and rather fine-grained, containing numerous irregular masses of chert. This cherty limestone is widespread south of Bullitt County where its thickness ranges from 3 to 8 feet. In many places it is underlain by thinner-bedded, gray, somewhat sandy limestone, 2 feet or more thick, in the lower few inches of which are crowded shells of *Ambocoelia umbonata*. The fauna of this cherty limestone includes such Hamilton species as *Favosites goodwini, Ambocoelia umbonata, Pentamerella* cf. *pavilionensis, Productella spinulicosta, Reticularia fimbriata, Rhipidomella vanuxemi, Spirifer varicosus, Stropheodonta concava,* and *Platystoma lineatum.*

The Casey limestone lies between the black shale and the Louisville limestone (Silurian) in southern Bullitt, Nelson, and Larue counties. Closer to the crest of the Cincinnati arch in Marion, Taylor,

Adair, and Russell counties it rests on progressively older Ordovician formations, with the Silurian strata entirely missing from the outcrop. In Cumberland County, and in the area across the south end of the Jessamine dome, the New Albany shale rests on Ordovician with both the Silurian and the Devonian missing.

Boyle limestone.—Foerste (16: pp. 10, 92) applied this name to the Devonian limestones south of Bullitt County where these strata differ in their typical lithologic and faunal characteristics from both the Jeffersonville and the Sellersburg of the Louisville area. As originally defined, the Boyle included the Duffin (15: p. 145) layer at the top and the Kiddville layer at the base, separated by a thick series of limestones which is in places richly fossiliferous and cherty. Savage (31: pp. 1–21) redefined the name by excluding the Duffin layer which he placed at the base of the black shale.

The most characteristic fossils of the Boyle limestone are thought to indicate its equivalency with some part of the Hamilton, but they are not typically those of either the Silver Creek or the Beechwood limestone members. The upper part, which is a cherty limestone, is the equivalent of Savage's Casey limestone. There is at the base of the Boyle in many places a thin layer of sandstone or sandy limestone that contains numerous fragments of teeth and plates of fishes, which Foerste (16: pp. 92–93) has called the Kiddville layer from a hamlet in Clark County. The lower part of the Boyle is more fossiliferous than the upper, the most common species being *Cystiphyllum americanum, Heliophyllum halli, Ambocoelia umbonata, Athyris spiriferoides, Camarotoechia sappho, Pentamerella pavilionensis, Spirifer granulosus,* and *Tropidoleptus carinatus.* These are diagnostic Hamilton species, but there are in some places a few associated species which also occur in rocks of Onondaga age.

General summary.—The Casey limestone is the most consistently represented member of the Devonian limestone, and is Hamilton younger than the Beechwood. The Jeffersonville and the Silver Creek (lower member of the Sellersburg) thin to disappearance in southern Jefferson County. The Beechwood has been recognized in a few places south of Bullitt County, as described for Casey, Barren, and Allen counties.

The Boyle limestone represents the entire Devonian limestone sequence south of Bullitt County where the typical subdivisions of the Louisville section can not be differentiated. Its upper limit is the Duffin layer, basal New Albany, and the lower limit is the Silurian. Such units as the Casey, the Beechwood, and the Kiddville can not everywhere be recognized.

CORRELATION

The Camden chert of Tennessee is the equivalent of the Clear Creek chert of Illinois, both lithologically and faunally. Dunbar (11: p. 87) demonstrated that both are Onondagan through faunal evidence and by the fact that the formations are separated by an erosional interval from the typical upper Oriskany strata which they overlie—the Little Saline in the case of the Clear Creek, and Harriman in the case of the Camden. The Little Saline limestone disappears toward the south and east in Illinois, probably due to erosion, and the Clear Creek chert rests directly on the Grassy Knob chert, from which it can be distinguished only by faunal studies.

The Clear Creek grades without a break in deposition into the overlying Dutch Creek sandstone, and the Dutch Creek in turn grades into the Grand Tower. Correlations of the Illinois and Missouri sections were made on paleontologic evidence, but the great physical differences suggest an alternative correlation as shown in Figure 4. J. M. Weller lists the following reasons for favoring this alternative correlation.

(1) In Missouri there is no apparent break between the Little Saline limestone and the overlying beds that have been referred to the Grand Tower, and it does not seem likely that the thick Clear Creek chert could separate them nearby in Illinois

(2) It seems unlikely that two formations as similar as the Beauvais and Dutch Creek sandstones should be persistently present at different horizons in neighboring areas, or if they were, that neither should be even suggested in the area of the other

(3) With this interpretation the Devonian sections of southwestern Illinois and southeastern Missouri become essentially similar except for a general thickening in a southward direction (37: p. 130).

Careful study of the faunas of the two areas must be made before this problem can be solved, not only species studies but the association of the faunules with their environments as reflected in the lithologic variations within the formations.

Savage (27) on the basis of coral reef structures correlated the Jeffersonville in Indiana principally with the upper part of the Grand Tower in Illinois. Workman (40) agreed with this correlation and suggested the equivalency of the Pendleton sandstone and the Dutch Creek. He also suggested that the Lingle and Alto formations might be limestone phases of the Chattanooga black shale.

UPPER DEVONIAN

The only upper Devonian limestone exposed in the area involved in this study is the Alto, reported to overlie the Lingle limestone dis-

conformably in Union County, Illinois, where it varies 40–70 feet in thickness. The Alto was described by Savage (28: pp. 169–78) and named from an exposure along a creek in Alto Township, Union County. It consists of a dark, siliceous shale and somewhat shaly limestone. In places it is almost lithographic and includes small chert nodules. The fauna is not particularly diagnostic of any one division of the Devonian, the more common fossils being *Chonetes scitulus*, *Cryptonella eudora*, and *Leiorhynchus mesocastalis*.

Subsurface Stratigraphy

The study of cuttings from approximately forty wells drilled into or through the Devonian strata of western Kentucky has served to

		TENNESSEE	ILLINOIS	MISSOURI	INDIANA	KENTUCKY	ALTERNATIVE CORRELATION ILLINOIS	ALTERNATIVE CORRELATION MISSOURI
UPPER DEVONIAN		BREAK	ALTO	BREAK	BREAK	BREAK	ALTO	BREAK
MIDDLE DEVONIAN	HAMILTON / GENESEE	SELLERSBURG	LINGLE	ST. LAURENT	SELLERSBURG: BEECHWOOD, SILVER CREEK, SPEEDS	SELLERSBURG: CASEY, BEECHWOOD, SILVER CREEK	LINGLE, MISENHEIMER, GRAND TOWER	ST. LAURENT
	MARCELLUS / PEGRAM	BREAK	MISENHEIMER	BEAUVAIS	BREAK	BREAK (BOYLE)	DUTCH CREEK	BEAUVAIS
	ONONDAGA	JEFFERSONVILLE, CAMDEN	GRAND TOWER, DUTCH CREEK, CLEAR CREEK	GRAND TOWER	JEFFERSONVILLE, PENDLETON	JEFFERSONVILLE	CLEAR CREEK	GRAND TOWER
		HARRIMAN	LITTLE SALINE	LITTLE SALINE	BREAK	BREAK	LITTLE SALINE	LITTLE SALINE

Fig. 4.—Generalized sections of Middle Devonian. Alternative correlation as suggested by Weller (37: p. 130).

confirm the zoning system suggested in an earlier preliminary report,[6] and has indicated probable correlations with the Devonian strata cropping out in neighboring areas.

The zoning of the formations below the Chattanooga shale was based on certain distinct microlithologic differences and the characteristics of the insoluble residues. For utilitarian reasons the numbering system adopted is the reverse of the usual geological procedure of starting with the oldest formation. Geologists engaged in subsurface oil-field work commonly zone from the top downward as this method permits new zones to be added if the field is later explored for deeper producing beds. If the correlations suggested in this paper are confirmed when additional data become available, the formation names should then be substituted for the zone numbers.

[6] Louise Barton Freeman, "A Sample Study of the Devonian in Western Kentucky," *Kentucky State Dept. Mines and Minerals*, Ser. 8, Bull. 4 (1939).

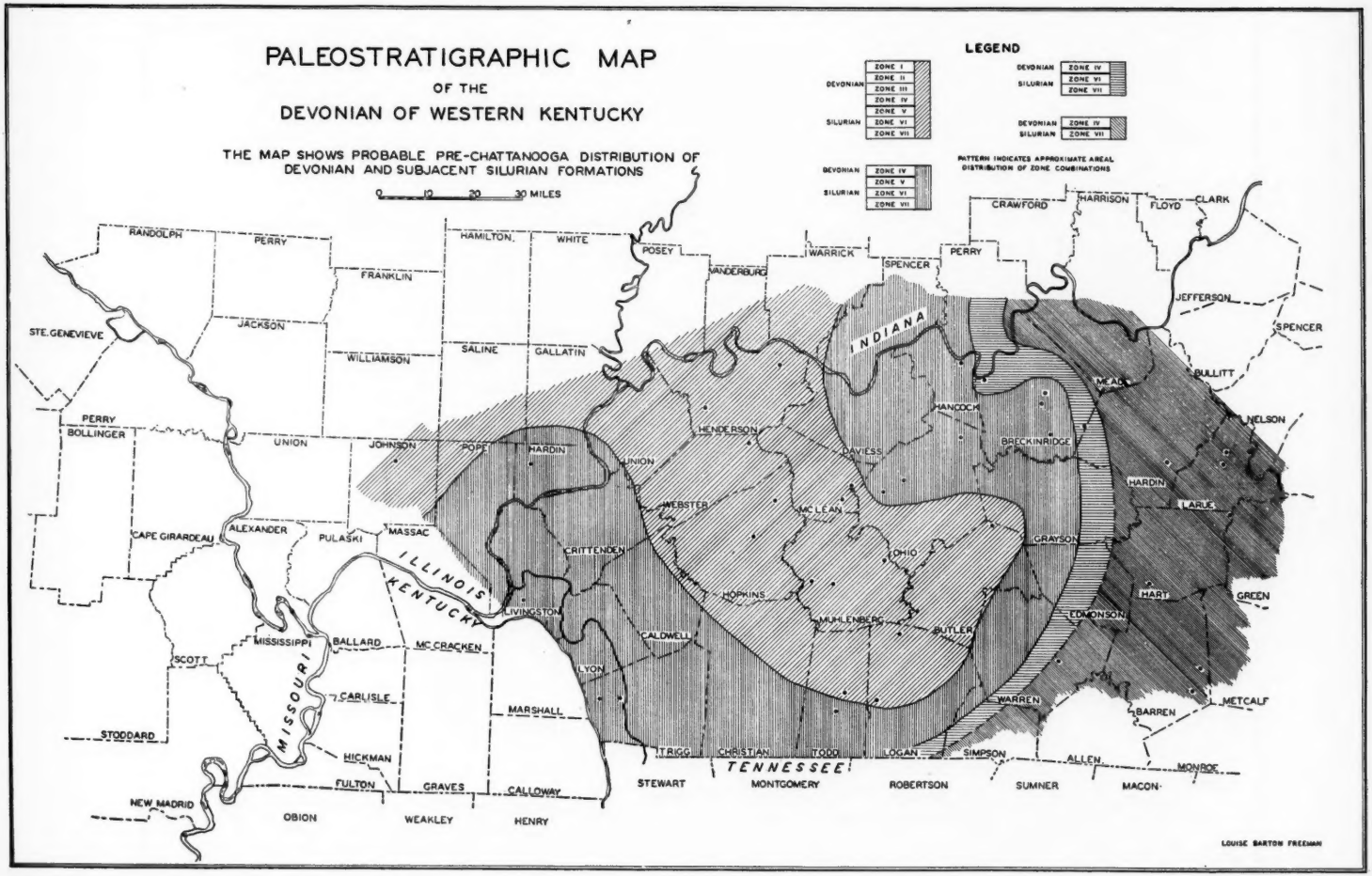

PALEOSTRATIGRAPHIC MAP
OF THE
DEVONIAN OF WESTERN KENTUCKY
THE MAP SHOWS PROBABLE PRE-CHATTANOOGA DISTRIBUTION OF DEVONIAN AND SUBJACENT SILURIAN FORMATIONS
0 10 20 30 MILES
LEGEND
DEVONIAN ZONE I
ZONE II
ZONE III
ZONE IV
SILURIAN ZONE V
ZONE VI
ZONE VII
DEVONIAN ZONE IV
SILURIAN ZONE V
ZONE VI
ZONE VII
DEVONIAN ZONE IV
SILURIAN ZONE VII
DEVONIAN ZONE IV
SILURIAN ZONE VI
ZONE VII
PATTERN INDICATES APPROXIMATE AREAL DISTRIBUTION OF ZONE COMBINATIONS
RANDOLPH
PERRY
FRANKLIN
JACKSON
STE. GENEVIEVE
WILLIAMSON
SALINE
GALLATIN
HAMILTON
WHITE
POSEY
VANDERBURG
WARRICK
SPENCER
PERRY
CRAWFORD
HARRISON
FLOYD
CLARK
JEFFERSON
SPENCER
BULLITT
NELSON
MEADE
HANCOCK
BRECKINRIDGE
HARDIN
LARUE
GRAYSON
HART
GREEN
EDMONSON
BARREN
METCALF
WARREN
BUTLER
LOGAN
SIMPSON
ALLEN
MONROE
TODD
CHRISTIAN
TRIGG
STEWART
MONTGOMERY
ROBERTSON
SUMNER
MACON
TENNESSEE
INDIANA
ILLINOIS
KENTUCKY
MISSOURI
PERRY
BOLLINGER
CAPE GIRARDEAU
ALEXANDER
UNION
JOHNSON
POPE
HARDIN
PULASKI
MASSAC
CRITTENDEN
UNION
HENDERSON
DAVIESS
WEBSTER
MCLEAN
OHIO
HOPKINS
MUHLENBERG
CALDWELL
LYON
LIVINGSTON
MISSISSIPPI
BALLARD
MCCRACKEN
SCOTT
CARLISLE
MARSHALL
STODDARD
HICKMAN
FULTON
GRAVES
CALLOWAY
NEW MADRID
OBION
WEAKLEY
HENRY
LOUISE BARTON FREEMAN

FIG. 5

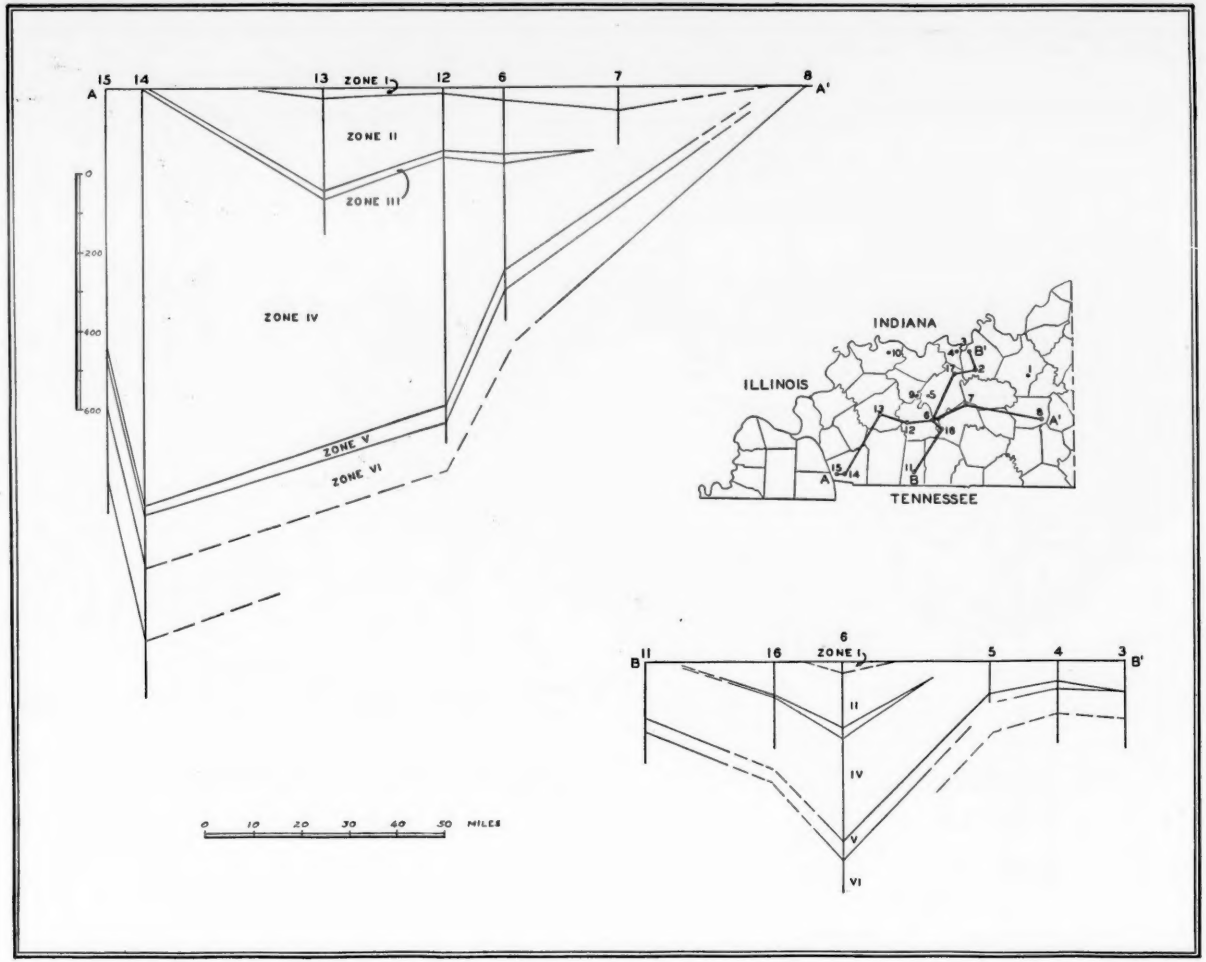
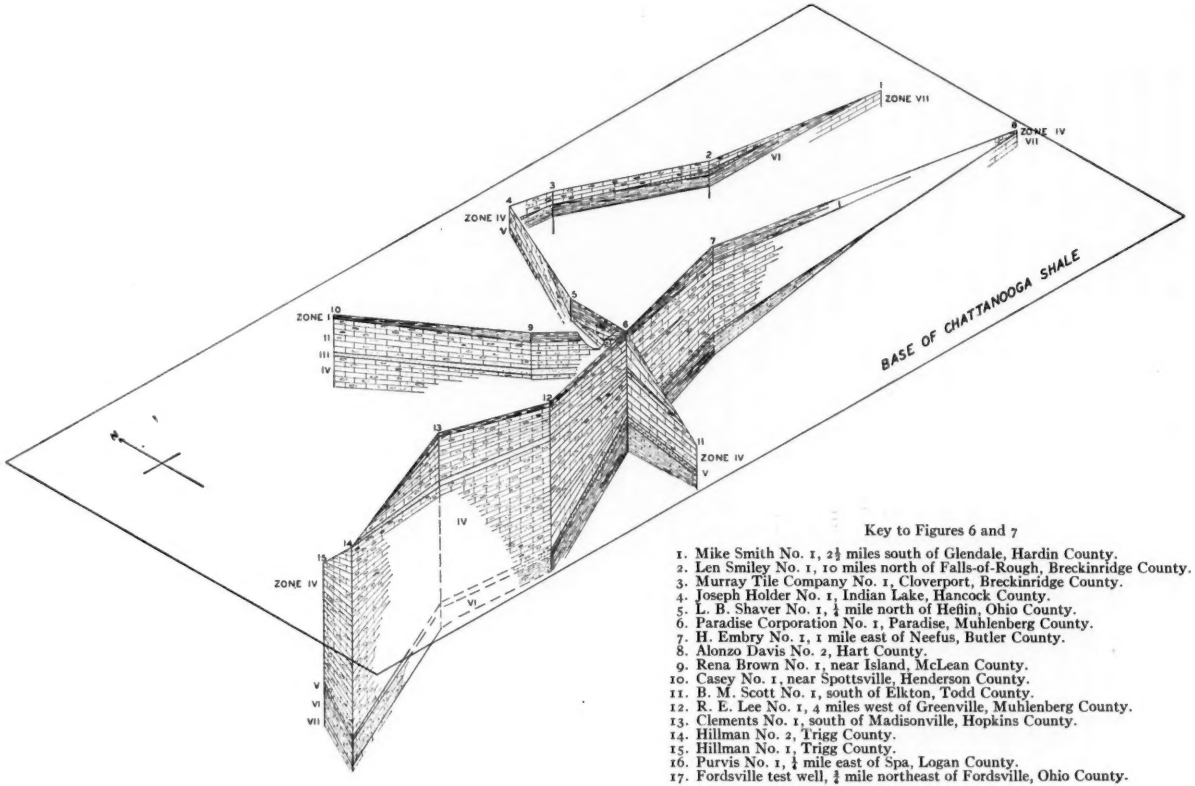


FIG. 6.—Sections across western Kentucky showing pre-Chattanooga structure and thinning of Devonian and Silurian south and east.

FIG. 6.—Sections across western Kentucky showing pre-Chattanooga structure and thinning of Devonian and Silurian south and east.



Key to Figures 6 and 7

1. Mike Smith No. 1, 2½ miles south of Glendale, Hardin County.
2. Len Smiley No. 1, 10 miles north of Falls-of-Rough, Breckinridge County.
3. Murray Tile Company No. 1, Cloverport, Breckinridge County.
4. Joseph Holder No. 1, Indian Lake, Hancock County.
5. L. B. Shaver No. 1, ¼ mile north of Heflin, Ohio County.
6. Paradise Corporation No. 1, Paradise, Muhlenberg County.
7. H. Embry No. 1, 1 mile east of Neefus, Butler County.
8. Alonzo Davis No. 2, Hart County.
9. Rena Brown No. 1, near Island, McLean County.
10. Casey No. 1, near Spottsville, Henderson County.
11. B. M. Scott No. 1, south of Elkton, Todd County.
12. R. E. Lee No. 1, 4 miles west of Greenville, Muhlenberg County.
13. Clements No. 1, south of Madisonville, Hopkins County.
14. Hillman No. 2, Trigg County.
15. Hillman No. 1, Trigg County.
16. Purvis No. 1, ¼ mile east of Spa, Logan County.
17. Fordsville test well, ¾ mile northeast of Fordsville, Ohio County.

FIG. 7.—Composite correlation diagram showing relation of Devonian and subjacent Silurian formations in western Kentucky.

A well drilled at Paradise[7] in Muhlenberg County penetrated stratigraphically deeper below the shale than any of the others having a complete section. For that reason the section encountered in it was used as a guide to which all other samples were compared.

Because the upper part of the Silurian also lends itself readily to zoning, and since the Lower Devonian sequences do not rest on the same Silurian formations in all areas, three zones are herein suggested for the Silurian strata most commonly encountered.

Figure 5 is a paleostratigraphic map indicating approximate areas where partial or complete zonal sections are represented beneath the Chattanooga. In the deepest portion of the basin all zones of the Devonian and subjacent Silurian are present. In a semicircular area around the center, opening to the north, the three upper zones of the Devonian rest on a complete Silurian zonal section. To the east there is a narrow strip where the lowest zone of the Devonian rests on the second Silurian zone, the upper zone, the Decatur limestone, having been removed. The available information indicates that the complete Silurian section continues westward. Still farther east, and higher on the flank of the Cincinnati arch, another Silurian zone, the upper Brownsport or Louisville, disappears. In this area if there are any Devonian rocks present, they are only a few feet in thickness and rest on the lowest zoned part of the Silurian.

Hence the map shows not only pre-Chattanooga areal geology but also the approximate stratigraphic section for the Devonian and upper part of the Silurian limestones. The fact that the Decatur and upper Brownsport limestones (Zones V and VI) are present south and west but disappear towards the Cincinnati arch suggests post-Silurian uplift of the arch—a reflection of the Caledonian movement elsewhere. The evidence from these subsurface studies affords the first indication that Silurian strata younger than Louisville were ever deposited in western Kentucky. The arch probably remained a positive structure during most of Devonian time, thus accounting for the non-deposition of some of the Lower Devonian strata. Pre-Chattanooga uplift with emphasis on the Nashville dome cut off the south end of the basin and permitted erosion of the upper Middle Devonian formations from the east, south, and west sides. Figures 6 and 7 show the wedging of some formations and the complete removal of others by pre-Chattanooga or pre-Helderberg erosion.

SILURIAN

ZONE VII

Underlying the upper Brownsport type Zone VI on the west side

[7] A list of the wells used in this study and their locations is given on page 700.

and extending well toward the center of the basin is red and gray mottled, fine-grained limestone of Bainbridge or Wayne characteristics. The red color is lost higher on the flank of the Cincinnati arch, but the texture of the limestone remains relatively constant. This results in a gray, fine-grained, magnesian limestone lithologically similar to the Louisville "high" on the side of the structure.

Additional zones may be added below Zone VII if deeper drilling makes available information regarding the characteristics of the lower formations of the Silurian and the Ordovician.

ZONE VI

This zone was reached in the deeper part of the basin only in the Paradise well, but most of the wells from Trigg County on the southwest to Breckinridge on the northeast encountered it. It is dark gray, dull, shaly, fossiliferous limestone, 50–60 feet in thickness. The residue is leached gray shale, rather coarsely porous, and shows fragmentary impressions of such fossils as bryozoans, brachiopods, and crinoid stem plates. In northern Ohio County and Hancock County there is near the top considerable limonite, showing a peculiar regular pore arrangement suggestive of fossil replacement. This material occurs as irregular fragments with no indication of what fossils are represented. The pores, which are 0.01 to 0.02 millimeter in diameter, are the openings to tubes which are arranged in parallel rows through the mass of the fragments.

A near-by well at Cloverport, Breckinridge County, at this horizon has considerable siliceous limonite in the sample. There is a small amount of blue-white chert in this zone, showing banding and in many places occurring as partial replacements of fossils. On the west side of the basin this horizon includes some glauconite. It is suggested that this argillaceous limestone, overlying typical Bainbridge and Louisville types of limestone and underlying the lithologic facies suggestive of Decatur, is equivalent to the upper Brownsport of the Tennessee section.

ZONE V

This zone is represented in all wells that penetrated the Silurian west of the Murray and the Howard wells in Breckinridge County. It varies from a few feet to as much as 30 feet in thickness, and disappears in the short distance between Indian Lake, Hancock County, and Cloverport, Breckinridge County, and between the Smiley and the Howard wells in central Breckinridge County, east of which it has not been encountered.

The cuttings are of white, coarsely crystalline limestone in the

top few feet, below which are introduced delicately tinted pink and pale green fragments. The limestone of the lower part of this zone is a mixture of buff and white. Acid treatment leaves a very small residue made up almost entirely of chalcedonic quartz or partial fossil replacements, which, in the lower part, reflect the yellow color of the original sample. Some of the lowermost samples show a little light green shale, and, particularly in the wells of Ohio, Breckinridge, and Hancock counties, an exceptionally high per cent of pyrite. Limestone of this type contrasts sharply with the Devonian cherty dolomites above, and with the argillaceous limestones of Zone VI below. On the basis of its lithology and position it is correlated with the Decatur (Middle Silurian) limestone of the Tennessee section.

DEVONIAN

ZONE IV

This zone is represented in its full extent in the Paradise well, where it is 300 feet thick. Most of the wells are drilled only about 100 feet into this zone. In a semicircular strip around the basin proper, open toward the north, the Chattanooga rests directly on some part of Zone IV (see Fig. 5). This zone thickens within a short distance west, partly due to stripping on the east as the flank of the Cincinnati arch is approached, and partly by deposition, as demonstrated by the difference in its thickness in the Paradise and Hillman wells in each of which the full section is present (Fig. 6).

Lithologically the strata of Zone IV resemble somewhat those of Zone II. Zone IV, however, is considerably more dolomitic and ordinarily contains two or more strata rich in glauconite. The chert in the upper part, which is mottled grayish tan and in some places dolocastic, may make up 40 per cent of the sample. There is a limestone interval about in the middle of Zone IV, which is less dolomitic and less cherty than the strata above and below, and which can be recognized in nearly every well which has been drilled deeply enough to encounter it. This limestone is white and coarsely crystalline, and the chert is white, chalky, and dolocastic. The per cent of chert and dolomite again increase in the lower part of the zone. The lower chert is mainly brown with white inclusions, some of which are undoubtedly sponge spicules, and others suggest radiolarian remains. In some cases the chert is translucent white with dull white markings. Cherts of this description have been recognized in the deeper wells in the main part of the basin and in the strip surrounding this area where the Chattanooga rests on some part of Zone IV.

The contact with the arenaceous Zone III above is sharply delineated, and the change from cherty, dolomitic limestone of the Devonian to the unmistakable Silurian limestone below is easily recognized.

Zone IV is tentatively correlated with the Clear Creek chert, the Grassy Knob (Oriskany) chert, and the underlying Helderberg cherts. Workman (40), in his studies of the subsurface Devonian of Illinois, has been unable to differentiate between these formations and in his paper refers them all to the Grassy Knob-Bailey.

ZONE III

This zone is present in all the wells studied in the basin proper and a suggestion of it appears directly under the shale as far west as the Hillman No. 2 well in Trigg County. The zone is in general thin, reaching its maximum known thickness of about 50 feet in wells in McLean and Hopkins counties. It is marked at the top by a sharp change from the cherty limestones of Zone II to white, pure, coarsely crystalline limestone which grades downward into a sandstone. In the southernmost wells the proportion of sand to calcareous material does not exceed 25 per cent. The sand grains are poorly sorted as to grade size, but they are all well rounded and frosted. The per cent silica and the grade size decrease near the base and near the top. In other words, the most uniformly coarse sand is found near the middle of the deposit. Wells in Henderson County have thinner sections of sandstone, but the grains are coarser and show some polishing in addition to the rounding and frosting. The western trend of this sandy horizon can not be outlined accurately at this time as there is no information available concerning the strata in the area between the wells in Hopkins and Muhlenberg counties, and the wells of Trigg and Livingston counties some distance west. It is probable that the sandstone strata are the equivalent of the Dutch Creek sandstone of Illinois, and possibly of the Pendleton sandstone of Indiana. Workman (40), of the Illinois Geological Survey, has suggested that the Pendleton and Dutch Creek are correlatives.

ZONE II

Zone II varies in thickness from 25 feet in the Darden well, Logan County, to 220 feet in the Clements well, Hopkins County. The Ramsey well in Hopkins County, and the Embry in Butler County, did not reach the base of Zone II. The rocks of Zone II are composed of white to light tan, coarsely crystalline, cherty limestone, slightly dolomitic. The residue makes up 5–50 per cent of the original and is mainly

dull, mottled, light tan and gray or white chert with a few black inclusions. The chert at the top is white or very light tan, but that near the base is darker brown with dolocasts rare. This basal chert breaks into thin flakes which are translucent with a dark oily luster, and they contain dark inclusions.

As in the case of Zone I, this cherty limestone is restricted to the deepest part of the basin with a connection into Illinois and Indiana toward the north. Contacts with the dark argillaceous limestone above and with the arenaceous limestone below are sharp and readily discerned even in a cursory examination of the samples. The zone is tentatively correlated with the Grand Tower limestone of southwestern Illinois and southeastern Missouri.

ZONE I

Zone I varies in thickness from 31 feet in the Paradise well to 76 feet in the Morris well in McLean County. The original samples show a dense, fine-grained, dark brownish gray, argillaceous limestone, in some places fossiliferous. These samples leave a large residue of very finely porous shale which is dark brownish gray near the top with light tan, more coarsely porous shale near the base. A little blue chert and pyrite may be present. The diminishing amount of shale residue downward and the increase of the chert content are easily recognizable markers for the base of Zone I.

As indicated on the accompanying map and diagram (Fig. 5 and Fig. 7) this zone is represented only in the wells in the deeper part of the basin from which its strata thin toward the south and east. The zone persists northward into Illinois where, judged by its lithologic character and position in the section, it is probably the equivalent of the Lingle, Misenheimer, and Alto formations.

LIST OF WELLS USED IN THIS STUDY[8]

Barron County, J. E. Eaton, drilled by Louisville Gas and Electric Company, 1 mile southwest of Temple Hill
Barren County, C. E. Glass, drilled by Louisville Gas and Electric Company, near Keno
Butler County, E. E. Brown, near Penrod
Butler County, (7) Minnie Embry, drilled by W. H. Ford, 1 mile southeast of Neefus
Breckinridge County, Davis No. 1, drilled by Allison *et al.*, 3 miles east of Harned
Breckinridge County, Fannie McCoy No. 1, drilled by Lion Oil Company, 3 miles east of Garfield
Breckinridge County, Ben Howard No. 1, drilled by Louisville Gas and Electric Company, 2 miles north of Constantine, near the Hardin-Breckinridge counties line
Breckinridge County, (3) Murray Tile Company No. 1, drilled by Galey and Flesher, Cloverport

[8] A number in parentheses before the name of a well indicates that it was used in the cross-sectional diagrams (Figs. 6 and 7).

Breckinridge County, (2) Len Smiley No. 1, drilled by H. C. Hume and A. J. Early, 10 miles north of Falls-of-Rough
Hancock County, (4) Joseph Holder No. 1, drilled by Galey and Flesher, 1 mile east of Indian Lake
Hardin County, L. L. Mathier, drilled by Louisville Gas and Electric Company, corner of Hardin, Nelson and Larue counties
Hardin County, (1) Mike Smith No. 1, drilled by Louisville Gas and Electric Company, 2½ miles south of Glendale
Hart County, (8) Alonzo Davis No. 2, drilled by Cumberland Petroleum Company
Hart County, Ransom Lewis No. 1
Henderson County, (10) J. E. Casey No. 1, drilled by Magnolia Oil Company, near Spottsville
Henderson County, Sheffer Heirs No. 1, drilled by Phillips Petroleum Company, near Corydon
Hopkins County, (13) Clements No. 1, drilled by Gulf Oil and Refining Company, south of Madisonville
Hopkins County, Parker No. 1, drilled by Phillips Petroleum Company, near Vendetta
Larue County, G. W. Beard No. 1, drilled by Louisville Gas and Electric Company
Larue County, Nannie Larue No. 1, drilled by Louisville Gas and Electric Company
Livingston County, H. L. Dunn, drilled by J. Harvey Dunn, south of Smithland
Logan County, Darden No. 1, near Russellville
Logan County, (16) R. V. Purvis, drilled by R. W. Gray and Wicklund Development Company, ¼ mile east of Spa
McLean County, (9) Rena Brown No. 1, drilled by South Penn Oil Company, south of Island
McLean County, L. E. Morris No. 3, drilled by Miller, Damron and Callas, Barrett Hill
Meade County, A. E. Hardaway No. 1, drilled by Louisville Gas and Electric Company, ¾ mile northeast of Big Spring
Muhlenberg County, (12) R. E. Lee, drilled by Ohio Oil Company, 4 miles west of Greenville
Muhlenberg County, (6) Paradise Corporation Well No. 1, drilled by South Penn Oil Company, at Paradise
Muhlenberg County, Rice Brothers No. 3, drilled by J. C. Ellis, near Friendship Church
Ohio County, (17) Corniferous test well at Fordsville, junction of three farms, the G. H. Roberts, G. E. Fuqua and S. Lancaster Estate, drilled by Galey and Stewart, Cumberland Petroleum Company, and Snowden and McSweeney
Ohio County, (5) L. B. Shaver No. 1, drilled by Callas, Stephenson and Galey, ¼ mile north of Heflin
Ohio County, Vance No. 1, near Beda
Todd County, J. N. Haddon No. 1, drilled by A. A. Peard, north of Elkton
Todd County, (11) B. M. Scott No. 1, drilled by J. A. Eubank, 1 mile east of Elkton
Trigg County, (15) Hillman No. 1 and (14) Hillman No. 2, drilled by Ada Belle Oil Company
Warren County, Lena Doyle No. 1
Webster County, J. R. Ramsey No. 5, drilled by Iley Browning, near Sebree

SAMPLE DESCRIPTIONS

Detailed sample descriptions are here given for the wells used in Figures 6 and 7, with the exception of those wells drilled with a rotary rig.[9] Such descriptions have been made for every set of samples studied for this report but it was not considered necessary to include such details for every well as much of the material would have been repetitious. Hence the data for only the most significant wells have been chosen for presentation.

[9] The number in parentheses before the name of the well indicates that it was used in the cross-sectional diagram (Figs. 5 and 6).

(1) MIKE SMITH NO. 1, HARDIN COUNTY

Depth in Feet

ZONE IV

845– 846 Limestone, some of which is dense brown, some light-colored; much black shale from above

ZONE VII

846– 851 Limestone, white and in places pale green, fine-grained with finely disseminated pyrite and a few fragments of green shale

– 861 Dolomite, greenish gray, finely crystalline, calcite only as fragments of crinoid plates

– 875 Dolomite as above with addition of some blue-white, dense, and some translucent and oölitic chert

– 915 Dolomite, brown, crystalline; little blue-white chert, some of which is disseminated in small particles through the dolomite

(2) LEN SMILEY NO. 1, BRECKINRIDGE COUNTY

ZONE IV

1,308–1,318 Limestone, slightly dolomitic, white, crystalline, rare fragments blue-white with included pyrite; crinoid plates partly replaced with silica

–1,323 Limestone, white, coarsely crystalline; some dark brown argillaceous limestone, in places with black inclusions, and in places showing irregular clustering of dark crystals

–1,326 Limestone, light tan crystalline, crinoidal, a few plates replaced with silica

–1,342 Limestone, rather fine-grained white to tan, slightly dolomitic; some chert, irregular masses of white enclosed in translucent brown, some dolocasts

–1,355 Limestone, white to tan crystalline, occasional fragments showing film of carbonaceous material on polished surfaces; 25–40 per cent chert, finely mottled, dense with brown inclusions

–1,359 Limestone, white to light tan crystalline; much less chert than above

ZONE V

–1,367 Limestone, white coarsely crystalline

–1,379 Limestone as above with introduction of brown, finely crystalline dolomite; a little pale gray or green dolomite

ZONE VI

–1,393 Limestone, white to tan crystalline, fossiliferous with partial replacement of crinoid plates with brown quartz; some slightly calcareous dark gray shale

–1,415 Limestone, very dark gray, argillaceous with some very fine sandy material, fossiliferous with fragments of brachiopods prominent

–1,430 Limestone, very argillaceous, leaving greenish, porous shale residue; some more crystalline limestone showing a few fragments of smooth ostracodes

ZONE VII

–1,436 Limestone, tan, coarsely crystalline, fossiliferous; few fragments argillaceous, and few scattered grains of fine sand

–1,446 Limestone, white crystalline, fossiliferous; some dark gray argillaceous and sandy limestone, the sand grains being very fine, and the shaly material green with some glauconite

–1,480 Limestone and dolomite, greenish gray argillaceous, some fine sand, slightly fossiliferous; about 50 per cent porous shale residue

–1,487 Some dolomite as above; some coarsely crystalline white to light gray limestone, fossiliferous with crinoid stem plates and a few smooth ostracodes

1,497–1,518 Limestone, white crystalline, slightly dolomitic; little dark gray calcareous shale; glauconite; some fine dolomite with very fine sand

(3) MURRAY TILE COMPANY NO. 1, BRECKINRIDGE COUNTY

ZONE IV

1,568–1,576 Limestone, crinoidal and a little gray argillaceous limestone; little blue-white translucent chert

−1,584 Limestone and dolomite, white crystalline; chert white and tan mottled with a few dolocasts
−1,606 Limestone, more dolomitic than above; less chert but dolocasts more numerous, some chert showing banding and being coated with drusy tan quartz
−1,615 Limestone, tan, dense, very little dolomite as rhombs in mottled tan chert; few large fragments of tan calcite from crinoid fragments
−1,637 Limestone, white coarsely crystalline; very little mottled tan and white chert and some drusy quartz

ZONE VI

−1,650 Limestone, gray, argillaceous, fossiliferous with rare smooth ostracodes and *Streblotrypa*
−1,655 Limestone, white coarsely crystalline and dolomitic; very little chert
−1,660 Dolomite, white to tan, finely crystalline; some tan porous shale in residue and secondary replacement of chalky chert
−1,681 Limestone, slightly dolomitic; more chert than above, some dense and dull white to light brown, some porous white, here and there blue-white fragments; pyrite; much bright red siliceous limonite in lower part
−1,700 Limestone and dolomite, finely crystalline, few chert fragments and porous shale in residue; little glauconite
−1,720 Limestone with some dolomite, coarsely crystalline; some oölitic chert
−1,737 Limestone, white to tan crystalline, crinoidal; little tan, argillaceous limestone; a few encrustations of crystalline quartz
−1,760 Limestone, slightly argillaceous, very fossiliferous with crinoid fragments, fenestrated bryozoans, rare ostracodes, a few brachiopod fragments with one complete *Ambocoelia*

ZONE VII

−1,765 Dolomite, gray, finely crystalline with little argillaceous material; quite fossiliferous with mainly crinoid stem plates
−1,770 Limestone, white and gray crystalline, some dark inclusions which may be phosphatic
−1,792 Dolomite, white, finely crystalline; little chert, some of which is porous and rotten; little gray crystalline limestone near base

(4) Joseph Holder No. 1, Breckinridge County

ZONE IV

1,751−1,765 Limestone, gray crystalline, some has dark inclusions, some has glauconite inclusions; crinoidal; few fragments of argillaceous limestone leaving residue of coarsely porous brown clay; few fragments of bluish chert, some as replacements of crinoid plates
−1,770 Limestone, tan crystalline with a little argillaceous material; residue is porous shale from argillaceous limestone and some fragments of chalcedonic replacements
−1,775 Limestone, dolomitic, white to tan crystalline; chert is mainly dull white and dolocastic; little chalcedony as replacements
−1,784 Limestone, dolomitic, white coarsely crystalline; chert is either chalky white and dolocastic, brown mottled with white spicular markings, or chalcedony
−1,810 Limestone, dolomitic, white to tan coarsely crystalline; very little chert, tan dolocastic, in places mottled dull tan to translucent
−1,815 Limestone, white to tan coarsely crystalline; no chert; little very finely crystalline quartz as coatings
−1,835 Limestone, white crystalline to dense brown finely crystalline; about 12 per cent chert, brown and tan mottled, and some brown with white markings

ZONE V

−1,846 Limestone, white and pink, coarsely crystalline; much pyrite
−1,850 Limestone as above with addition of some pale green limestone and rare grains of fine sand
−1,873 Limestone, coarsely crystalline with buff staining; much pyrite in residue and some papery greenish gray shale in lower part

ZONE VI

–1,908 Limestone, greenish, argillaceous with many crinoid remains

(5) L. B. Shaver No. 1, Ohio County

ZONE IV

2,282–2,295 Limestone, slightly dolomitic, very coarsely crystalline; 10 per cent chert white chalky, rare dolocasts

–2,306 Limestone, light tan crystalline; 30 per cent chert, some white mottled dull and translucent, some very dark brown and dense, and some brown translucent with dark flecks and white spicules

–2,330 Limestone, very slightly dolomitic, white; little dull white to drusy chert; little fissile green shale near base

(6) Paradise Corporation No. 1, Muhlenberg County

ZONE I

3,385–3,419 Limestone, white to gray crystalline, some fine-grained rounded sand; little argillaceous limestone leaving spongy shale residue

ZONE II

–3,427 Limestone, white, crystalline and dolomitic; less than 5 per cent residue of chert, dull to vitreous and some dolocastic

–3,449 Limestone, white to light tan, crystalline and dolomitic; chert residue, some dull, mostly vitreous bluish white or mottled dull and translucent, a few dolocasts

–3,494 Limestone, white, crystalline, dolomitic; little chert, some tan and dull, some drusy

–3,498 Limestone, white to tannish gray, dull as above but more cherty; chert, amber-brown to opalescent, breaking into thin sharp fragments some of which show dark flecks, some showing dolocasts

–3,518 Limestone, much lighter in color than above, white with rare bluish gray flecks and some tannish dull to crystalline; very little chert

–3,527 Limestone, finely crystalline, brown; very little dull, mottled brown chert

–3,536 Limestone, tan, finely crystalline; about 35 per cent chert, some vitreous amber-brown with dark flecks, some very finely porous and mottled tan

–3,538 Limestone, tan and siliceous as above with about 30 per cent residue of finely porous tan chert

ZONE III

–3,547 Limestone, white to light tan, finely to coarsely crystalline; no chert

–3,567 Limestone, coarsely crystalline, white; 5–20 per cent fine to medium size sand, all grains rounded and frosted

–3,572 Limestone, dolomitic, white, crystalline; some fine rounded and frosted sand as above; some dolocastic white chert

ZONE IV

–3,585 Limestone, dolomitic, white to light gray, mottled; about 15 per cent chert, light gray with a few dark markings and dolocasts, much mottled with white spicular inclusions, some tan similarly marked with white inclusions

3,587–3,627 Limestone, dolomitic, white to light gray; chert, white with a few dolocasts and a few fragments showing spicular markings as above

–3,649 Limestone as above; chert is more dolocastic and has a few fragments of blue-gray chert and tiny doubly terminated quartz crystals; some glauconite

–3,670 Limestone, dolomitic, fine white to light tan; very little chert as above; some glauconite inclusions and pyrite

–3,675 Limestone, dolomitic, more gray and crystalline than above; about 5 per cent chert, mottled and slightly dolocastic

3,680–3,696 Limestone, dolomitic as above, much coarser-grained; about 20 per cent chert, grayish semi-translucent background with fine white markings and few dolocasts

–3,740 Limestone, white crystalline; some chert, chalky white and dolocastic; little drusy quartz and pyrite

–3,770 Limestone, dolomitic, white crystalline; about 20 per cent chert, white, spicular, occasional dolocasts and dark inclusions

–3,775 Limestone, dolomitic, white to cream with about 20 per cent cream chert, dull to translucent
–3,834 Limestone, dolomitic, light tan crystalline; chert, tan, some spicular, some dolocastic
–3,863 Limestone, tan, dolomitic and cherty; chert, very dolocastic, some translucent with white spicules, some blue-white; glauconite in upper part
–3,866 Limestone, dolomitic, tan finely crystalline; chert, very dolocastic, tan mottled with white spicules; glauconite

ZONE V

–3,868 Limestone, white, coarsely crystalline, dolomitic; some glauconite
–3,879 Limestone, white, coarsely crystalline, dolomitic, with pale pink and green staining; very small residue of drusy quartz and pyrite
–3,885 Limestone, white crystalline and buff with pink and green staining; the drusy quartz residue shows yellow stain
–3,890 Limestone as above but more green and considerable glauconite

ZONE VI

–3,905 Limestone, gray, finely silty, some greenish; some bluish gray chert
–3,910 Limestone, gray, crystalline and argillaceous, fossiliferous; many brownish crinoid stem plates in the gray matrix; little blue-gray chert
3,918–3,972 Limestone, dense, gray, argillaceous, fossiliferous as above; residue is porous gray silt and clay with a little glauconite

(7) H. Embry No. 1, Butler County

ZONE I

1,896–1,915 Shale, black, slightly calcareous; residue is porous brown shale
–1,924 Shale as above; some limestone, gray, dense, some argillaceous, some crystalline; few fragments of blue chert and some pyrite
–1,979 Limestone, gray-brown, some argillaceous leaving porous tan shale as residue; some crystalline limestone
–1,985 Limestone, less argillaceous than above, some crystalline and having spotted appearance due to enclosed pyrite and glauconite; few fragments of smooth ostracodes

ZONE II

1,986–1,994 Limestone, white to light gray, coarsely crystalline, crinoidal; a little fine sand
–2,010 Limestone, dolomitic, white crystalline; chert is white to cream, dolocastic, some banded with fillings of crystalline quartz; little glauconite
–2,022 Limestone, white, crystalline; chert is chalky, soft and porous with only a little translucent white chert
–2,065 Limestone, white to tan, coarsely crystalline, crinoidal, fossiliferous; no chert

(8) Alonzo Davis No. 2, Hart County

ZONE VI

375– 382 Limestone, white crystalline; little very fine sand; a few dolomite rhombs enclosed in black shale
– 389 Limestone, light gray to white with chert, some of which is intergrown with limestone. Residue is chert, blue-white translucent, breaking with conchoidal fracture
– 396 Dolomite, white, evenly crystalline; little chert as above; sand grains

ZONE VII

– 410 Dolomite, white, more coarsely crystalline than above, with thin streak of green, fissile shale; some angular porosity in dolomite
– 438 Dolomite, white, coarsely crystalline with regular pore space; a few grains are bluish in color; flakes of green, fissile shale
– 452 Dolomite, gray, less regularity of crystal size and less porosity; little finely disseminated silica and pyrite
– 459 Dolomite, white, coarsely crystalline with high porosity; a little greenish dolomite, more finely crystalline with a little finely disseminated silica; a few oölites of dolomite, each coated with fine crystals of tan dolomite

(9) Rena Brown No. 1, McLean County

ZONE I

3,474–3,479 Limestone, dark gray; very small residue of dark brown and gray shale; some pyrite and translucent chert
–3,505 Limestone, dark gray argillaceous, leaving residue of soft brown shale; occasional blue chert fragments and pyrite
–3,520 Limestone, dark gray argillaceous as above

ZONE II

–3,529 Limestone, white and brown, coarsely crystalline; some brown chert and fine sugary quartz
–3,556 Limestone, dolomitic; chert, brown, some dolocastic and some with brown oily lustre
–3,616 Limestone, white crystalline; little white and brown chert, some of which shows fossil molds; few dolocasts
–3,677 Limestone, brown, dolomitic; chert is brown and white, much of the brown with oily luster, a little is dolocastic

ZONE III

–3,714 Sand, some iron-stained, fairly well sorted, well rounded and frosted grains with calcareous cement
–3,720 Sand, coarse grained, white, mostly angular but many grains show rounding and frosting, then fracture

ZONE IV

–3,746 Limestone, dolomitic, white; chert is dense, white to mottled grayish tan, dolocastic, some with dark inclusions; a few sand grains; high per cent of pyrite some of which shows dolocasts
–3,817 Limestone, dolomitic, white; chert is mottled white to gray, some dolocasts; some chert fragments show encrustations of tiny quartz crystals

(10) Casey No. 1, Henderson County

ZONE I

3,999–4,003 Limestone, dense, brown, some crystalline and some argillaceous; residue of finely porous clay material and brown or blue-white chert
–4,021 Limestone, slightly dolomitic, dense to crystalline, brown; about 25 per cent brown chert
–4,038 Limestone, dense, brown argillaceous
–4,057 Limestone, dolomitic, white to light tan, very coarsely crystalline; only a little argillaceous residue

ZONE II

–4,066 Limestone, dolomitic, white, coarsely crystalline; chert, tan and white mottled with a few dolocasts
–4,071 Limestone, dolomitic, white to tan crystalline; about 25 per cent chert, most of it brown with some inclusions of white siliceous bryozoan fragments, some dolocastic
–4,107 Limestone, cream to tan, finely crystalline; less chert than above, some mottled white and some translucent tan
–4,115 Limestone, slightly dolomitic, cream-colored, crystalline; little cream-colored siliceous material, mainly as partial replacements of bryozoans and crinoids
–4,127 Limestone, tan, coarsely crystalline; chert, dense and tan
–4,197 Limestone, dolomitic with the dolomite in small brown rhombs, crinoidal; very little chert as fine, slightly dolocastic, dull material
–4,211 Limestone, white to brown crystalline; chert, about 10 per cent, dark brown, some with dark flecks, some with white inclusions, some dolocastic

ZONE III

4,217–4,225 Limestone, slightly dolomitic, white, coarsely crystalline; little rounded and frosted sand, mostly large grains
–4,228 Sandstone, dolomitic, very coarse grained, large rounded and frosted grains, many of them showing secondary crystal growth
–4,239 Limestone, dolomitic; some sand as above, some white chert with gray splotches and dolocasts

ZONE IV

–4,242 Limestone, dolomitic, white, in places marked with gray; about 10 per cent chert, white to light gray with white markings, dolocastic

–4,254 Limestone, dolomitic, finely crystalline, tan; about 50 per cent chert, dolocastic, grayish tan, some brown with spicular markings
–4,315 Limestone, dolomitic, white, coarsely crystalline; chert, chalky white, dolocastic
–4,327 Limestone, dolomitic, creamy white, coarsely crystalline; little chert, white with dull white spicular markings
–4,359 Limestone, dolomitic, white very coarsely crystalline; much crystalline pyrite and glauconite
–4,384 Limestone, slightly dolomitic, creamy white, coarsely crystallline; little chert, creamy white with spicular markings, and a few fragments of brown with white spicular markings

(11) B. M. Scott No. 1, Todd County

ZONE IV
1,233–1,240 Limestone, white, coarsely crystalline, crinoidal; some pyrite
–1,270 Limestone, dolomitic, white, coarsely crystalline; chert dull mottled white, with dolocasts
–1,285 Limestone, white crystalline, less cherty than above; much glauconite as bright green inclusions and bright stains on limestone
–1,294 Limestone, white to gray, crystalline; little blue chert
–1,300 Limestone, white, coarsely crystalline; chert white and translucent, some of which is banded with crystalline quartz; some glauconite
–1,308 Limestone, white, coarsely crystalline as above but with no chert or glauconite
–1,314 Limestone, white to gray, crystalline, some spotted with dark material; chert white and translucent, a little blue chert; fossiliferous; a little glauconite
–1,336 Limestone, white to tan, finely crystalline; chert, translucent, some spicular and some showing banding with crystalline quartz
–1,345 Limestone, tan, finely crystalline; chert, amber-like brown to blue transparent with dark flecks
–1,373 Dolomite, brown, rhombs distinct, showing some porosity; chert brown, some chalky white with a few dolocasts, some translucent with fine spicular markings; little glauconite

ZONE V
–1,383 Limestone, white, coarsely crystalline with some pink and green fragments; no chert
–1,388 Limestone as above with introduction of a little more argillaceous and green

ZONE VI
–1,390 Limestone, greenish gray, argillaceous, enclosing tan crinoid stem plates; pyrite crystals enclosed in limestone
–1,409 Same kind of limestone as above, very fossiliferous with fragments of brachiopods, ostracodes, and crinoids; some glauconite

ZONE VII
–1,414 Limestone, white and pink, coarsely crystalline, fossiliferous with much calcareous, orange-red shale
–1,441 Limestone, white, finely crystalline, some tannish pink dolomite, very fossiliferous
–1,463 Dolomite, very finely crystalline, gray with some coarsely crystalline white limestone and crinoid fragments; fragments of blue-white translucent chert
–1,487 Limestone, gray, slightly argillaceous, crinoidal; chert opalescent; some glauconite

(15) Hillman No. 1, Trigg County[10]

ZONE IV
830– 843 Limestone, dull gray, argillaceous; some blue chert and pyrite

[10] (12) R. E. Lee No. 1, Muhlenberg County, drilled many years ago and a complete set of samples was not available.
(13) Clements No. 1, Hopkins County, rotary samples from which a detailed study of this kind could not be made.
(14) Hillman No. 2, Trigg County, similar to Hillman No. 1.

– 863 Limestone, white, crystalline; some brown chert and a little blue chert; pyritic shale and some glauconite
– 873 Limestone as above but chert is lighter in color and some is opalescent
– 900 Limestone, dolomitic, white, less cherty than above; chert is chalky white, dolocastic
– 905 Limestone, dolomitic, tan to white; little white chert, angular quartz grains
– 925 Limestone as above; tan chert; rare rounded and frosted sand grains; some glauconite
–1,080 Dolomite, white crystalline; dull white dolocastic chert
–1,160 Limestone, dolomitic; much light gray chert with finely disseminated pyrite; slightly glauconitic
–1,170 Limestone, less dolomitic than above and more glauconite
–1,225 Limestone, light tannish gray, crystalline, fossiliferous with no identifiable fossil; much pale blue aragonite; some glauconite
–1,250 Limestone, dolomitic, white; little white chert
–1,300 Limestone, light gray, crystalline, very fossiliferous with many fragments of brachiopods; chert, gray with texture of novaculite; glauconite
–1,405 Limestone, dark gray with much dark blue-brown, translucent chert, some of which is flinty with conchoidal fracture
–1,495 Limestone, dense to fine-grained, brown; chert lighter in color making up large part of sample; some glauconite
–1,520 Limestone, white, crystalline, fossiliferous; some bright blue chert and glauconite
–1,530 Limestone, tan; some blue chert and some light gray chert
–1,535 Limestone as above; a few fragments of bentonite-like shale with large biotite inclusions

ZONE V

–1,565 Limestone, light gray, crystalline; much chert, blue-white and translucent
–1,570 Limestone, darker in color, and some of it is leached white; little bentonite-like shale

ZONE VI

–1,600 Limestone, dark, argillaceous, showing some leaching
–1,625 Limestone, dark gray-brown, finely crystalline, argillaceous

ZONE VII

–1,655 Limestone, very coarsely crystalline, white, pink and green with some red argillaceous limestone
–1,720 Limestone, darker red, some green; crystals of red calcite; all argillaceous
–1,760 Limestone as above with introduction of a little green calcareous shale
–1,795 Limestone, finely crystalline, light gray-green, argillaceous
–1,800 Limestone with red calcite streaks
–1,830 Limestone, red and white, argillaceous, some clear red calcite; some glauconite
–1,835 Limestone, light gray, finely crystalline
–1,870 Shale, gray, hard, coarse-textured, little fine sand; pyrite
–1,900 Limestone, argillaceous, gray, fossiliferous

(16) Purvis No. 1, Logan County

ZONE II

1,468–1,475 Limestone, white, crystalline, fossiliferous, leached; some brown dolomite with oil staining
–1,479 Limestone, white to light gray, crystalline; rare fragments of translucent blue-white chert
–1,494 Limestone, white, coarsely crystalline, chalky
–1,510 Limestone, white to cream, coarsely crystalline as above; some blue-white translucent, almost opalescent chert
–1,517 Limestone, tan, crystalline, crinoidal
–1,527 Limestone, tan, dense to finely crystalline; some brown slightly argillaceous limestone
–1,540 Limestone, white to tan crystalline with brown amber-like chert with dark inclusions

ZONE III

–1,545 Limestone, white to tan crystalline; little brown chert as above; some gray-white blocky chert; many rounded and frosted and grains enclosed in the limestone

ZONE IV

–1,572 Limestone, dolomitic, light tan, some having leached appearance; much chert, dull to semi-translucent, dolocastic; little glauconite

–1,588 Limestone, white to tan, with leached appearance; chert as above with addition of a few tan translucent fragments having white spicular markings; little glauconite

–1,610 Dolomite, white to tan; much chert, translucent to dull with many dolocasts; much glauconite

–1,615 Limestone, white, crystalline; some chert, blue-white translucent; little glauconite

–1,632 Limestone, white, crystalline to gray with dark flecks; chert is blue-white translucent, but some is distinctly blue

–1,653 Limestone, white, crystalline; chert rare and blue; few glauconite inclusions

–1,661 Limestone, light gray, crystalline, some with dark flecks; some of chert has dark flecks and fine spicular markings

–1,680 Limestone, dolomitic, white to light tan; much chert, some translucent tan and some dull with occasional doloca ts and faint spicular markings

(17) CORNIFEROUS TEST WELL, OHIO COUNTY[11]

ZONE IV

2,038–2,041 Limestone, tan, finely crystalline, little argillaceous, few fragments of blue-white translucent chert

–2,050 Limestone, slightly dolomitic, white to light tan, crystalline; chert, some mottled tan, some translucent, a little brown with white spicular markings

–2,059 Limestone, white to tan, coarsely crystalline; very little chert, some of which is drusy

–2,075 Limestone, tan, crystalline, some coarsely crystalline and crinoidal; little chalcedony in residue

–2,087 Limestone, white to tan, coarsely crystalline, leached looking; little mottled tan chert

–2,096 Limestone, tan, crystalline; about 30 per cent chert, mostly tan mottled, much is brown semi-translucent with dark flecks

–2,105 Limestone, white, coarsely crystalline; no chert

–2,121 Limestone, dolomitic; about 50 per cent chert, white, chalky, dolocastic, showing some spicular markings

ZONE V

–2,145 Limestone, white, coarsely crystalline, some pink and green limestone; much pyrite

CONCLUSIONS

CORRELATION

On the basis of the zonal system introduced in this article, the correlation of the Devonian and subjacent Silurian formations of western Kentucky is as indicated in Figures 6 and 7. These correlations are necessarily tentative and will be subject to revision as new material becomes available.

The absence of the Decatur and upper Brownsport, Zones V and VI, from the sections high on the flank of the Cincinnati arch, and

[11] Located at junction of three farms: G. H. Roberts, G. E. Fuqua, and S. Lancaster Estate, near Fordsville.

their presence on the west side of the basin indicates some post-Middle Silurian and pre-Devonian uplift and erosion. It is suggested that this may be the evidence hitherto lacking for a reflection of the Caledonian mountain-building episode in the Mississippi Valley and Cincinnati arch areas.

The thickening of the Lower and lower Middle Devonian to the southwest suggests that the source of the thick cherts and dolomites was in that direction. The Kentucky strata may represent the seaward facies of the Arkansas and Texas novaculites.

Post-Hamilton warping of the basin, perhaps as a result of relative east-west uplift occasioned by movement of the Nashville dome, served to cut off the southern end of the syncline. This resulted in the preservation of a complete section of Lower and Middle Devonian strata in the deepest part, and the stripping of the Hamilton and most of the Onondaga from the east, south, and west sides. All or nearly all of the Devonian sediments were removed from the region high on the Cincinnati arch side of the basin before deposition of the Chattanooga shale.

RELATION TO PETROLEUM POSSIBILITIES

To date there have been no wells of commercial importance drilled which produce from the Devonian rocks of western Kentucky. This does not, however, rule out the possibility of the existence of oil and gas reservoirs. Lower and Middle Devonian strata in the area from which the Upper Devonian limestones have been eroded must have been subjected to dolomitization and recrystallization in many places with resultant horizons of potential reservoir rock. This must also apply to the Decatur limestone just west of the area of its complete removal, and also to the pre-Louisville limestones where the Louisville has been removed. Larue County gas production from the Laurel dolomite is an illustration of such a situation. The scarcity of data makes it possible to indicate only within wide limits the areas where exploratory work might be advisable.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 4 (APRIL, 1941), PP. 713-723, 5 FIGS.

STUDY OF SEDIMENTATION AND STRATIGRAPHY OF LOWER MISSISSIPPIAN IN WESTERN MICHIGAN[1]

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ABSTRACT

The lower Mississippian of western Michigan is composed of the Coldwater, Ellsworth, and the upper part of the Antrim formations. These formations in the western part of the state differ so markedly from the formations of the eastern side of the state that different basins and times of sedimentation are suggested.

The basal member of the Coldwater is red fossiliferous limestone with some red shale; several very fossiliferous zones rich in crinoids, ostracods, and bryozoans with some brachiopods, gastropods, cephalopods, and pelecypods occur locally; clay-ironstone concretions are more abundant in the section discussed than elsewhere in the state; and the "Coldwater lime" which in many places is light gray dolomite rather than limestone, has embedded crystals of secondary dolomite and "pepperings" of glauconite.

The Ellsworth is present only in the western part of the state and is gray and gray-green shale with gray dolomite zones. Small pyrite concretions and some spore cases are present throughout the formation.

In places near the contact of the Ellsworth and Coldwater there is a buff oölitic limestone in which the central core of the oölites is light brown dolomite. Where the oölites are absent the zone is brown crystalline dolomite which in many places produces gas. Stratigraphically this zone is at the horizon of the Berea sandstone of the Michigan basin but lithologically it is dolomite containing grains of rounded frosted sand.

The green shales of the Ellsworth grade into, and alternate with, the black shales of the Antrim so that it is difficult to determine the true top.

Since the lower Mississippian does not crop out in the area discussed, all correlation must be made from well logs and samples. Recent drilling developments have added considerable information and future work will undoubtedly define the paleogeography.

The formations representing the lower Mississippian in Michigan have always been considered as unimportant shale sections and have received very little study. With the recent drilling developments in Allegan, Kent, and Ottawa counties good samples prove that this western area differs markedly in its sedimentary history and presents several interesting stratigraphic problems.

Subsurface studies of the region were made from records of nearly 200 wells from which samples (cable-tool) were available. However, as samples of cuttings from some of the thinner stratigraphic sections are very questionable, the interpretation from them also may well be questioned.

The oldest formation in the section discussed is the Antrim shale which caps the producing Traverse limestone and is considered by

[1] Read by title before the Association at Chicago, April 11, 1940. Manuscript received, October 19, 1940. Published by permission of R. A. Smith, State geologist. This study is a part of the study of the entire Mississippian being undertaken by the Survey.

[2] Geologist, Michigan Department of Conservation, Geological Survey Division, Capitol Savings and Loan Building.

many geologists to be the source bed for Traverse oil. The sea in which the Antrim shale was deposited in Michigan was widespread over a large basin area and must have received a great quantity of macerated vegetation from low swamplands to have given the characteristic black-to-brown color to the shale which drillers sometimes term "coffee shale." Pyrite concretions and spore cases are common but evidently in this early Antrim sea conditions were too toxic to sustain organic life as very few fossils have been found.

When this area had received 150–200 feet of sediment, a broad warping movement took place. According to Newcombe[3] there was a downwarping toward the northwest presumably along a shallow area acting as an axis extending from Calhoun County north through Eaton, Clinton, Gratiot, Isabella, and Clare (Fig. 1). From a study of samples obtained since Newcombe's report was published it seems evident that this shallow axial area extended as far west as Montcalm, Ionia, and Barry counties and acted as a barrier to limit the eastward extension of the sea which came in from the north and west and deposited thick, predominantly green, sediments called the Ellsworth shale by Newcombe.[4]

If the Antrim sea still prevailed on the eastern side of the barrier, it can be assumed that there was considerable fluctuation of the two seas, especially at either end of the barrier, thus causing sedimentation from different sources and accounting for the alternation of green Ellsworth and brown Antrim shales. Drillers find it difficult to pick a good top for the Antrim and usually call the first brown shale coming in with the green shale "light Antrim," and the true black-to-brown shale is designated as "dark Antrim."

The alternation of green and black shales has somewhat the appearance of varves and might possibly be due to a cycle of climatic changes during deposition as suggested by Margaret Stearns Bishop.[5]

Over the barrier very little if any Ellsworth shale was deposited but it thickens within a very short distance westward to an average thickness of 450–500 feet throughout most of the area, and in a trough extending northwest and southeast through Ottawa County, the shale is more than 600 feet thick in places.

A longer period of deposition in the Antrim sea rather than the considered greater depth of the Antrim basin on the eastern side of the

[3] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38* (1933), pp. 78–79.

[4] *Ibid.*

[5] Margaret Stearns Bishop, "Isopachous Studies of Ellsworth to Traverse Limestone Section of Southwestern Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 12 (December, 1940), pp. 2150–62.

FIG. 1.—Map showing southwestern Michigan area. Dashed line along trend of barrier axis. Solid line, location of cross section (Fig. 2).

barrier probably accounts for the much thicker black Antrim shale. Near the close of Antrim deposition east of the barrier, a sea progressed from the southeast and in it the gray Bedford shales and the Berea sandstones were deposited. In no place do these Berea-Bedford sediments approximate the greater thickness of the Ellsworth shale.

Above the alternating green and black Ellsworth Antrim shales (which might be called "Elltrim") is a green shale—the true Ellsworth. The green color of this shale was no doubt derived from the sediments coming from the iron-bearing areas at the north either in primary deposition or by later reduction of the red ferric, to the green ferrous, sediments. The shale is characterized by thin zones of light gray, gritty, and in places sandy dolomite; it also contains spore cases and pyrite concretions, which look somewhat like minute golf balls. Samples from the Ellsworth section in several wells in northern Allegan County are light brown shale which seems to indicate that there the Ellsworth had been much weathered. However, it is possible that the color may have been produced by overheating the samples as they were washed and dried.

Near the close of Ellsworth time, warping and tilting of the basin again occurred but the barrier remained a controlling factor and limited the eastward advance of a sea which must have come in from the north and in which limestone and dolomite were deposited (Fig. 3). The extreme southwestern corner of the area under discussion was elevated above the level of the limestone deposition and thus received none of the later sediments which were laid down in a northwest-southeast trough.

This dolomitic zone has been called "Berea" and is carried as "Berea horizon" in well logs as it is in the same stratigraphic position as the Berea of the eastern part of the state. However, the term is lithologically incorrect for in this area the rock is dolomite rather than sandstone although it has some sand grains which drill up free. As shown in Figure 2, the sand grains are scattered along the western shore counties but in places they occur in the green shales of the upper Ellsworth as well as in the crystalline dolomite. They are medium to fine, well rounded and frosted grains. It seems highly probable that they are wind-blown from some sandstone formation cropping out on the southwest.

The limestone is buff-colored and dense and ranges from 10 feet to 40 feet in thickness. The dolomite is predominantly brown although there is a little gray dolomite, and the greater part is very crystalline. The fact that it is so crystalline and in many places so porous suggests that the dolomite is secondary in origin. This area of dolomite may

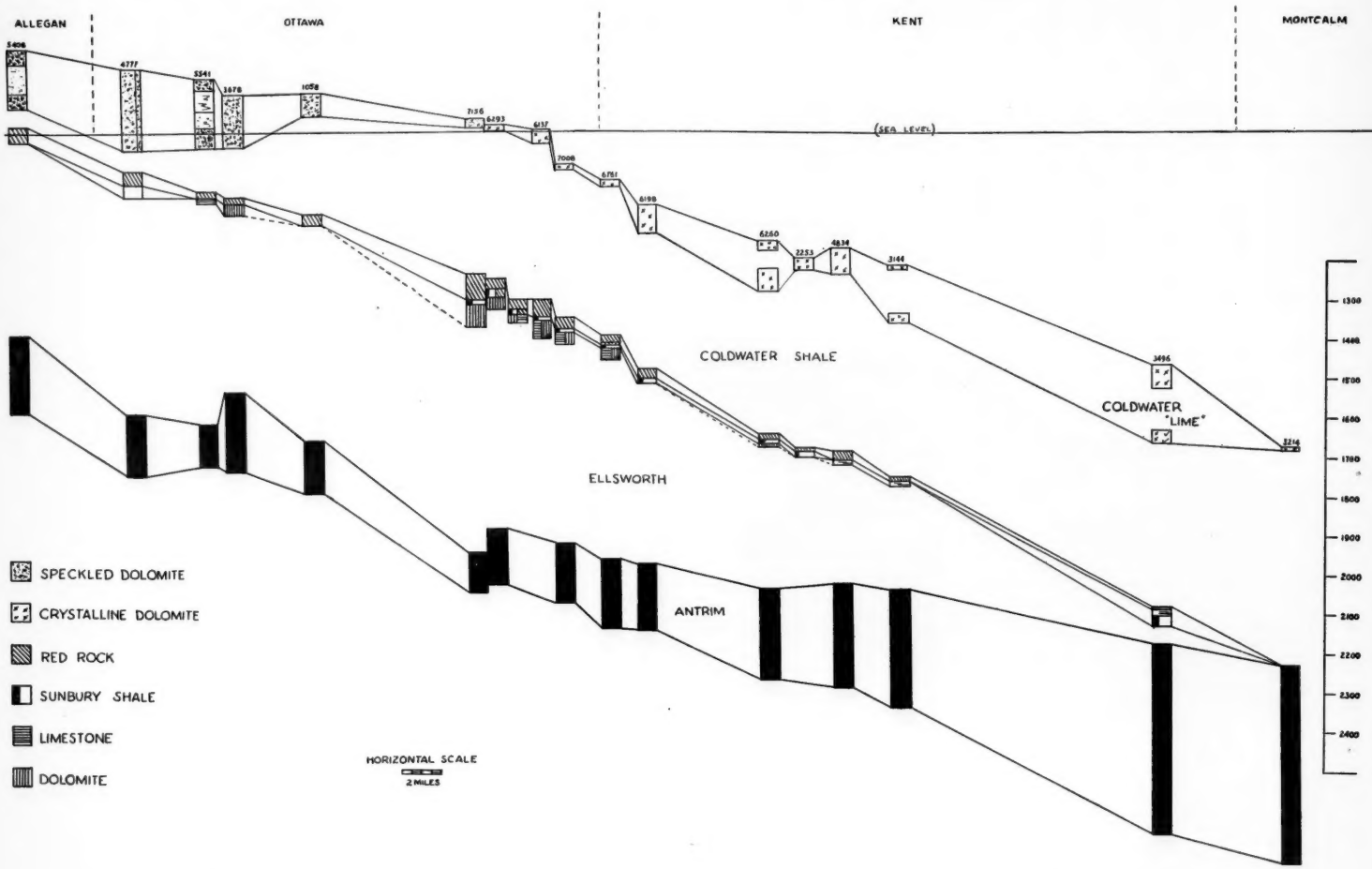
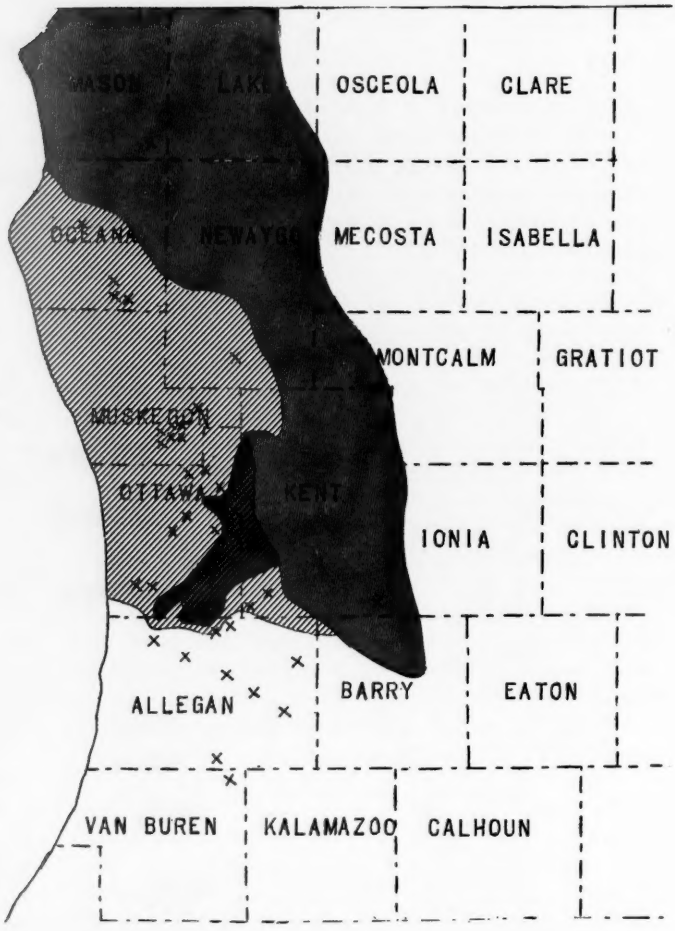


FIG. 2.—Southwest-northeast cross section from Allegan County to Montcalm County. Numbers of wells are "Permit" numbers.



APPROXIMATE EXTENT OF LIME AND DOLOMITE OCCURRING ABOVE THE ELLSWORTH SHALE

- Dense buff limestone
- Brown crystalline dolomite
- Oolitic area with both limestone and dolomite
- Rounded sand grains

FIG. 3

represent a shore line or perhaps a phase, climatic or diastrophic, which caused shore conditions in the original limestone sea and subjected the calcareous sediments to erosion, leaching the calcite and enriching the magnesium content.

Along the border of Kent and Ottawa counties there is a very interesting oölitic zone and here both the buff limestone and the brown dolomite are present. The oölites are spherical and commonly drill free. They are composed of concentric layers of buff-colored limestone with central cores of crystals—many of them perfect rhombs—of brown dolomite. Eardley[6] considers this structure to be like some of the oölites which he has studied[7] from Great Salt Lake which have evolved as concentric layers around faecal pellets of the brine shrimp *Artemia gracilis*, as nuclei. Further study will be necessary to prove to this writer the origin of these oölites.

Where it produces gas in Ravenna Township, Muskegon County, Wright Township of Ottawa County, and Walker Township of Kent County, the dolomite zone is especially pronounced as dark brown, coarsely crystalline, porous dolomite.

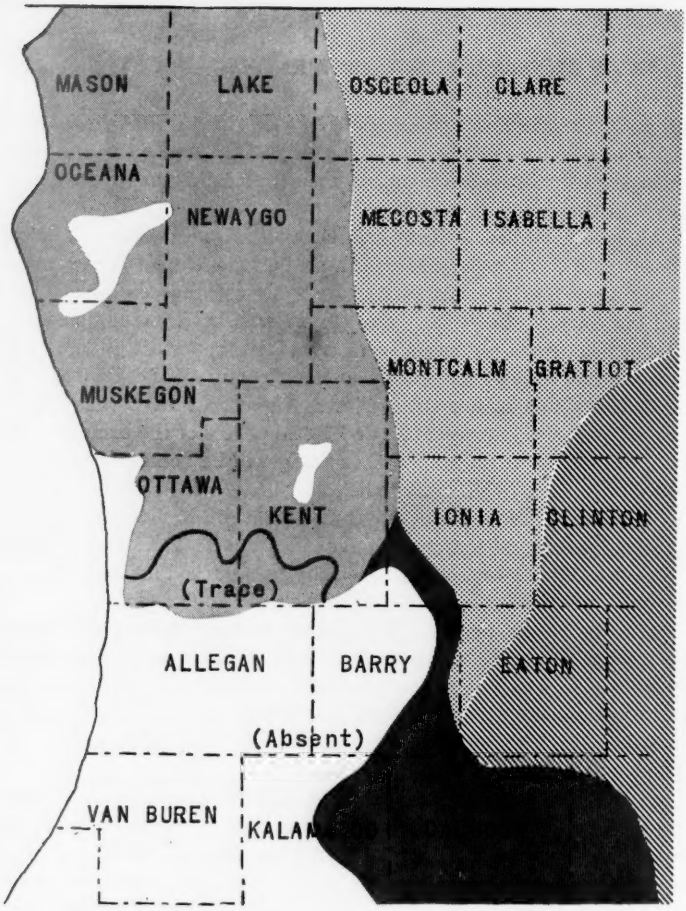
Samples from some wells, particularly in this producing area, show green Ellsworth shale above the dolomite and above the green shale a black shale which is stratigraphically equivalent to the Sunbury. Therefore, the top of the Ellsworth is placed below the black shale where the black shale is present, or below the Red Rock where it is absent.

Should this black shale formation be called Sunbury? It is definitely a black shale which averages about 25 feet in thickness in the main northern region where it overlies the limestone and dolomite and in several wells its thickness is 75 feet. The sea in which the shale was deposited did not cover the southwestern corner of the area discussed as it transgressed southeastward over the green Ellsworth shale (Fig. 4).

In the barrier area where there was little if any Ellsworth, thin, gray dolomite zones which show a little green coloration (glauconite?) were deposited with the black Sunbury shales. A few feet of gray shale is ordinarily present to separate the typical black Antrim from this black so-called Sunbury. Evidence derived from sample studies of wells in this area is confusing and it is difficult to determine whether the gray shale, dolomite, and black shale were deposited in one sea undergoing changing conditions or whether the lower gray shale repre-

[6] A. J. Eardley, Michigan Academy of Science, discussion.

[7] *Idem*, "Sediments of Great Salt Lake, Utah," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 10 (October, 1938).



APPROXIMATE EXTENT OF BLACK "SUNBURY" (?) SHALE

- Typical Sunbury shale with a Berea-Bedford section below
- Black shale and a little dolomite with green coloration (Antrim below)
- Black shale with Red Rock above and dolomite or limestone below
- Black shale with Ellsworth shale below

FIG. 4

sents a transgressing Bedford sea. Eastward the typical Sunbury lies above the Berea-Bedford section and it probably came in from the east.

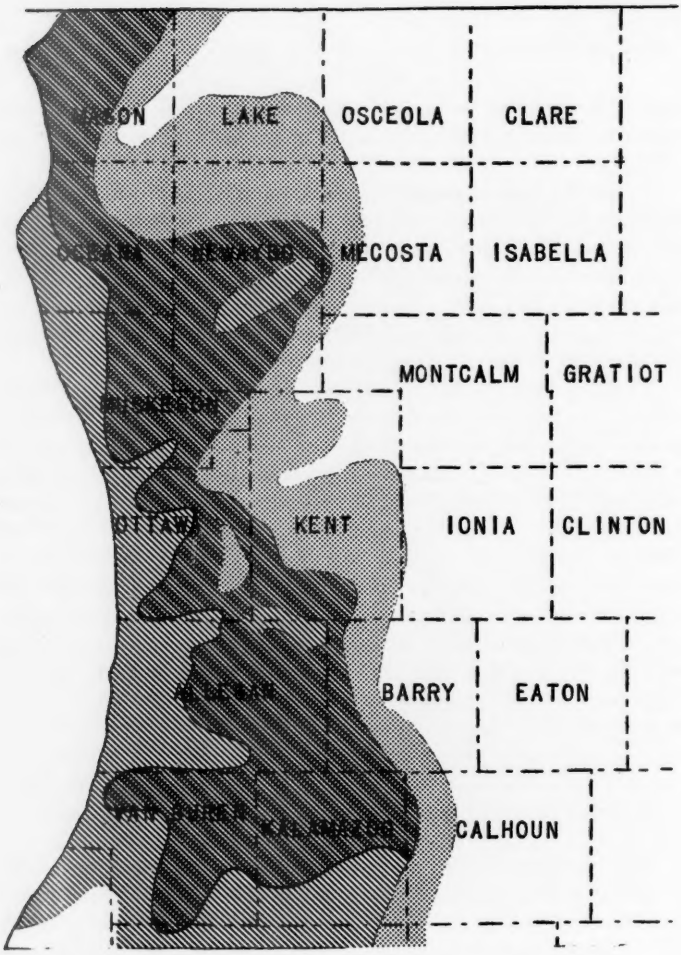
Above the Sunbury-Ellsworth are the thick Coldwater shales. A general downwarping of the central Michigan basin after Sunbury time caused the disappearance of the barrier and a general deepening of the basin. In this basin a thick section of shales was deposited but local variations of depth, climate, source of sediments, and other conditions caused the deposition of limestones and shales of varying color and impurity during Coldwater time.

Basal Coldwater is designated as Red Rock because of the characteristic red color. It is present throughout the entire area except in the extreme southwestern corner where the Coldwater formation is absent. It is difficult to give a generalized description of the Red Rock as it varies laterally and vertically in lithologic character and in thickness. In Barry, Calhoun, and Eaton counties it is nearly everywhere red shale but elsewhere it is either limestone or dolomite with some red shale above it. The samples from many wells show as much, if not more, buff, dense, fossiliferous limestone as red limestone but all the limestone may appear red because it is coated with a red color derived from the shales above. Some red limestones and dolomites have the appearance of reworked material whereas in other samples the more common fossils—crinoid columns, horn corals, and some ostracods are in a good state of preservation and show no evidence of having been reworked. The red coloring was probably derived from weathered material and possibly some iron oxides from land masses on the north and west.

The Coldwater sea was widespread and existed for a long time. Sediments 600–800 feet in thickness were deposited in most of the basin but as much as 1,000 feet of sediments were deposited through Montcalm and Ionia counties where the barrier had previously existed.

Shifting conditions of deposition from land to the open sea are shown by the alternation of gray sandy shales (which are commonly very micaceous and show that the land source was not far away) and the numerous limestone and dolomite zones. In places the gray shales are locally very muddy and soft; in other areas the shale is flaky and brittle.

Samples from wells in the northern and eastern parts of the area show numerous dolomite zones. Samples from the southern part have much hard brown shale mixed with the gray shales. At an outcrop of the Coldwater shale in Branch County there is a zone of brown disk-shaped concretions of clay-ironstone with a central mass of galena, sphalerite, or calcite which occurs in a 20-foot exposure of gray shale.



APPROXIMATE EXTENT OF COLDWATER "LIME"

- Speckled dolomite without glauconite
- Speckled dolomite with glauconite
- Crystalline dolomite with glauconite
- Crystalline dolomite without glauconite (Zones common throughout Coldwater section - no definite horizon)

FIG. 5

Apparently there are several concretionary zones throughout the section of the Coldwater and the hard brown shaly material found in the samples is from drilled-up concretions.

Fossiliferous limestone zones rich in crinoids, ostracods, and bryozoans with some brachiopods, gastropods, cephalopods, and pelecypods are common but are evidently the result of purely local conditions as cross sections of the area fail to show them at any continuous horizon.

The so-called "Coldwater lime" (Fig. 5) is a little more persistent and has often been used as a marker horizon, although it is a poor one. "Speckled dolomite" can be used to describe this member where it is light gray dolomite matrix with embedded grains of light brown dolomite. "Pepperings" of a dark green mineral, probably glauconite,[8] are found in it and also in the gray shale which accompanies the dolomite. This glauconite is well rounded in some of the samples examined and may represent reworked glauconite from a northern outcrop, such as the Hermansville.

Cross sections show that on the outer rim of the basin only a thin interval separates the speckled dolomite from the Red Rock, but basinward the interval thickens considerably. Also on the outer rim of the basin the dolomite is much thicker, indicating that a trough trending northwest and southeast received the deposition of the speckled dolomite sea.

Eastward the dolomite is crystalline rather than speckled, although it occurs at about the same horizon and contains a little glauconite. Farther east and especially north the crystalline zones are common throughout the Coldwater gray shale section and indicate no definite horizon.

The Coldwater is the first rock below the glacial drift in the southwestern part of the area discussed but from northern Allegan, southwestern Barry, and northeastern Kalamazoo counties northward it is overlain by the Marshall sandstones. Some samples show typical Coldwater shales in the Marshall section which may suggest a recurrent sea in some localities—another problem.

As it has been the intent of the writer to show that the western and southwestern area of Michigan represents a different basin of sedimentation from the rest of the state throughout much of lower Mississippian time, a relatively large area has been described very generally. More detailed work in restricted areas and stratigraphic sections will be necessary to delineate further the sedimentation and stratigraphy.

[8] From microscopic examination made by William Davies, Michigan State College, East Lansing, Michigan.

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ANTRIM-ELLSWORTH-COLDWATER SHALE FORMATIONS IN MICHIGAN[1]

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Jackson, Michigan

ABSTRACT

The shale sequences between the overlying Marshall sandstone and the underlying Traverse limestone group were investigated along two lines of sections, one northeast and southwest across the central part of the basin, and the other, north and south along the western side. Samples of cuttings from wells spaced about 10 miles apart were the basis for the study.

Three major shale units exist, namely in ascending order, the black or dark brown Antrim, the gray or gray-green Ellsworth, and the gray or blue-gray Coldwater.

Evidence was found for the following conclusions. First, the Antrim thins out noticeably from east to west and the upper two-thirds interfingers with the lower half of the Ellsworth. Second, the Ellsworth is confined to the western counties and where studied is almost uniform in thickness. Third, a wedge-like extension of the "Berea" sandstone occurs on the eastern side of the basin. It is thickest along the line of the section at Saginaw Bay and disappears before the middle of the state is reached. A thin gray shale of Coldwater type, above the upper Antrim, has been called the Bedford. The Sunbury, a thin black shale bed, of Antrim type, resting directly on the "Berea," is a mappable unit in the eastern counties only.

Several type lithologies are found in many interfingering and separate lenses. Altogether, the lenses build up a shale series of somewhat uniform thickness (approximately 1,500 feet thick) but the separate units, each dominantly of an individual lithology, have interfingering lateral relations to each other.

INTRODUCTION

The extent and relationship of the three major shale formations which lie between the top of the Traverse limestone and the bottom of the Marshall sandstone were studied from the cuttings of twenty-two wells. These three formations are the black or dark brown Antrim, the green or gray-green Ellsworth and the gray or blue-gray Coldwater. A wedge of sandstone within the shale section in the eastern side of the basin has been generally correlated with the Berea of Ohio.

The lithology of the cuttings was studied microscopically, strip logs were prepared and transferred to two diagrams, and strata were matched and joined in what appeared to be the most probable relationships. In view of the lenticular and interfingered nature of the entire sequence, many of the jagged lines showing interfingering are merely interpretative. In general, however, the relations are evident and may be accepted without the support of diagnostic fossils.

[1] A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Science, in the University of Michigan. Manuscript received, January 22, 1941.

[2] 1404 Fourth Street.

ANTRIM SHALE

Type locality.—The black shales of Michigan, which are called Antrim, were first cited in a report by Douglass[3] in 1841, to occur on Sulphur Island, in Lake Huron, on the shore of the mainland south of this island, on the north shore of Pine (Charlevoix) Lake, in Charlevoix County and along the coast of Grand Traverse Bay, Lake Michigan. He did not name them but considered them "equivalent to the shales of western New York" which are known to be Upper Devonian in age.

In 1861, Winchell[4] included the same black shales, an overlying green shale, and a fine-grained, somewhat argillaceous sandstone and gritstone in his Huron group. He correlated this group with the Portage group of New York.

However, Rominger,[5] in 1876, believed that the name Huron should be applied only to the basal black shale in Winchell's Huron group because the strata overlying these shales contain fossils present in the Cuyahoga shale of Ohio, regarded as being of Mississippian age by Ohio geologists and Winchell. He correlated the shales with the Genesee of New York since he thought the shales in Michigan rested directly on the beds of the Hamilton group.

Wright,[6] in notes edited by Lane in 1895, applied the name St. Clair to the black shale and higher strata which were identified with the Ohio, Erie, Cleveland, and Bedford shales.

Lane,[7] in 1901, proposed to substitute the name Antrim for the name St. Clair because the latter name was pre-occupied. He did not specify any definite type locality for the Antrim shale but stated

> that on account of the exposures of shale which occur . . . along the coast of Grand Traverse Bay, T. 32 N., as described in the 1841 report [footnote] 3, I have suggested Antrim, the name of the county in which the exposures last mentioned occur.

Morse[8] suggests that the place which exhibits the exposures noted by Lane is located about 1 mile south of Norwood, Charlevoix County,

[3] C. C. Douglass, *Fourth Ann. Rept. State Geol. Michigan Senate No. 16* (1841), p. 105.

[4] Alexander Winchell, "Geology, Zoology and Botany of the Lower Peninsula," *First Bien. Rept. Progr. Geol. Survey Michigan*, Pt. 1 (1861), pp. 71–80.

[5] Carl Rominger, "Geology of the Lower Peninsula," *Geol. Survey Michigan*, Vol. III, Pt. 1 (1876), pp. 64–65.

[6] C. E. Wright, "The Geology of Lower Michigan," *Geol. Survey Michigan*, Vol. V., Pt. II (1895), p. 21.

[7] A. C. Lane, *Michigan Miner.*, Vol. 30, No. 10 (1901), p. 9.

[8] M. Morse, unpublished manuscript.

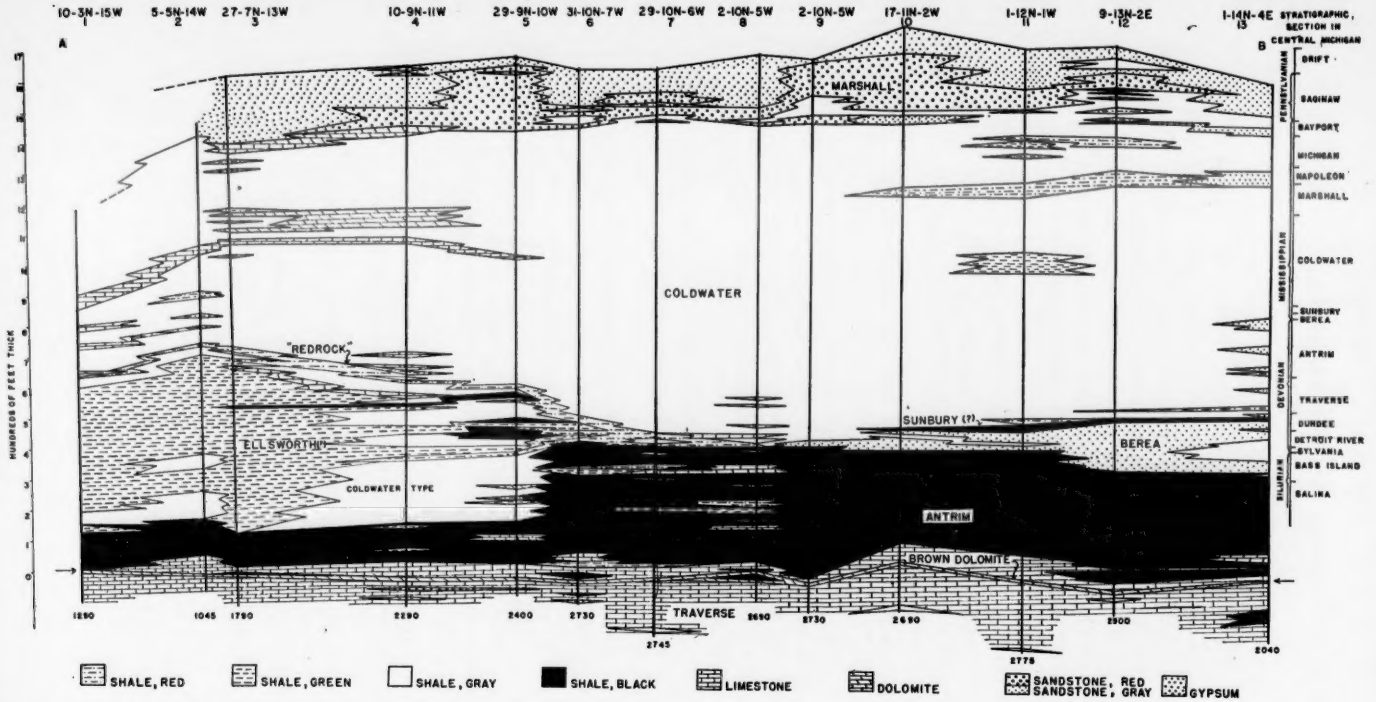

FIG. 1.—East-west cross section between points *A* and *B*, Allegan and Bay counties, respectively. Lenticular reconstruction and correlations are mostly imaginative but represent what writer believes to be most logical interpretation. Columns were matched by vertical shifting so as to show best the stratigraphic relations. No datum plane was used; hence, structure is mostly flattened out. Elevation of dolomite (indicated by arrow) in relation to sea-level, is given at bottom of each column.

LOCATION OF WELLS

No.	*Permit*	*County*	*Sec.*	*Twp.*	*R.*	*Name of Well*	*Company*	*Elevation, Feet*
1	5538	Allegan	10	3 N.	15 W.	James Overbeck 1	Haze & McGill	637.1
2	6817	Ottawa	5	5 N.	14 W.	Huyser 2	Freeman Oil	700.1
3	6293	Ottawa	27	7 N.	13 W.	M. Wisniswski 1	Smith Petroleum	661.3
4	6115	Kent	10	9 N.	11 W.	Davis 1	Wicklund	778.
5	3144	Kent	29	9 N.	10 W.	Plank 1	Associated Petr.	859.
6	4477	Montcalm	31	10 N.	7 W.	Hansen 1	Hirzel Leland	887.
7	3081	Montcalm	29	10 N.	6 W.	Russell 1	Old Dutch	850.
8	2395	Montcalm	2	10 N.	5 W.	Barger 1	Eastern Gulf	787.
9	2889	Montcalm	2	10 N.	5 W.	Fisher 1	Eastern Gulf	787.
10	2471	Gratiot	17	11 N.	2 W.	Walter 1	Mountain Oil	753.
11	3210	Gratiot	1	12 N.	1 W.	Redman 1	Gulf	696.
12	5422	Midland	9	13 N.	2 E.	Hepinstall 1	Weller	633.
13	4080	Bay	1	14 N.	4 E.	Marston 1	Gulf	595.

along the southwest boundary of Sec. 2, T. 32 N., R. 9 W., Antrim County, Michigan.

Lithology.—Newcombe[9] describes the Antrim as essentially brown to black to dark gray bituminous shale with many concretions concentrated in a zone near the base. The observations of this study agree with these, and the following details may be added. The beds near the bottom are black shale with here and there lenses of light gray shale or limestone. The beds are uniformly black in the middle of the formation, becoming lighter toward the top. Devonian fossils have been found in the upper part.[10]

Relation to Traverse group.—The Antrim black shale is separated from the true Traverse formation below by a transitional zone consisting of lenses of limestone and dolomite, and black, green and only rarely red shale. There is a distinctive brown dolomite layer which varies in thickness from 5 to 10 feet, in the transitional zone. As it was found in each well studied by the writer, it is indicated in Figures 1 and 2 as a continuous layer. As typical Antrim black shale does not occur below this dolomite, it is suggested that this layer may mark the break between the Traverse and Antrim formations.

Horizontal and vertical distribution.—The thickness of the formation varies from 100 to 450 feet, with the greatest thickness occurring along the line of section on the eastern side of the state. Figure 1 shows that the Antrim thins out toward the west (wells 5 and 6) and interfingers with the green or gray Ellsworth shale. The thickness of the formation from Saginaw Bay southwestward for 50 miles is about 400 feet but only the lower 150 feet continues to the western part of the state. Along the western side and toward the southwestern corner the much thinned black shale is under the Ellsworth except for minor transitional lenses. The color becomes more uniformly black toward the east.

ELLSWORTH SHALE

Type locality.—The blue and light gray shales above the Antrim were first described, in 1855, by Douglass[11] from an outcrop on Grand Traverse Bay, in T. 31 N.

Later, in 1861, Winchell[12] described similar beds on the east shore of Grand Traverse Bay, nearly opposite the north end of Torch Light

[9] R. B. Newcombe, "Oil and Gas Fields of Michigan," *Michigan Geol. Survey Pub. 38*, Geol. Ser. 32 (1933), p. 47.

[10] M. Morse, unpublished manuscript.

[11] C. C. Douglass, "Rocks of Michigan," *Trans. State Agri. Soc.*, Vol. VI (1855), p. 299.

[12] Winchell, *op. cit.*, p. 72.

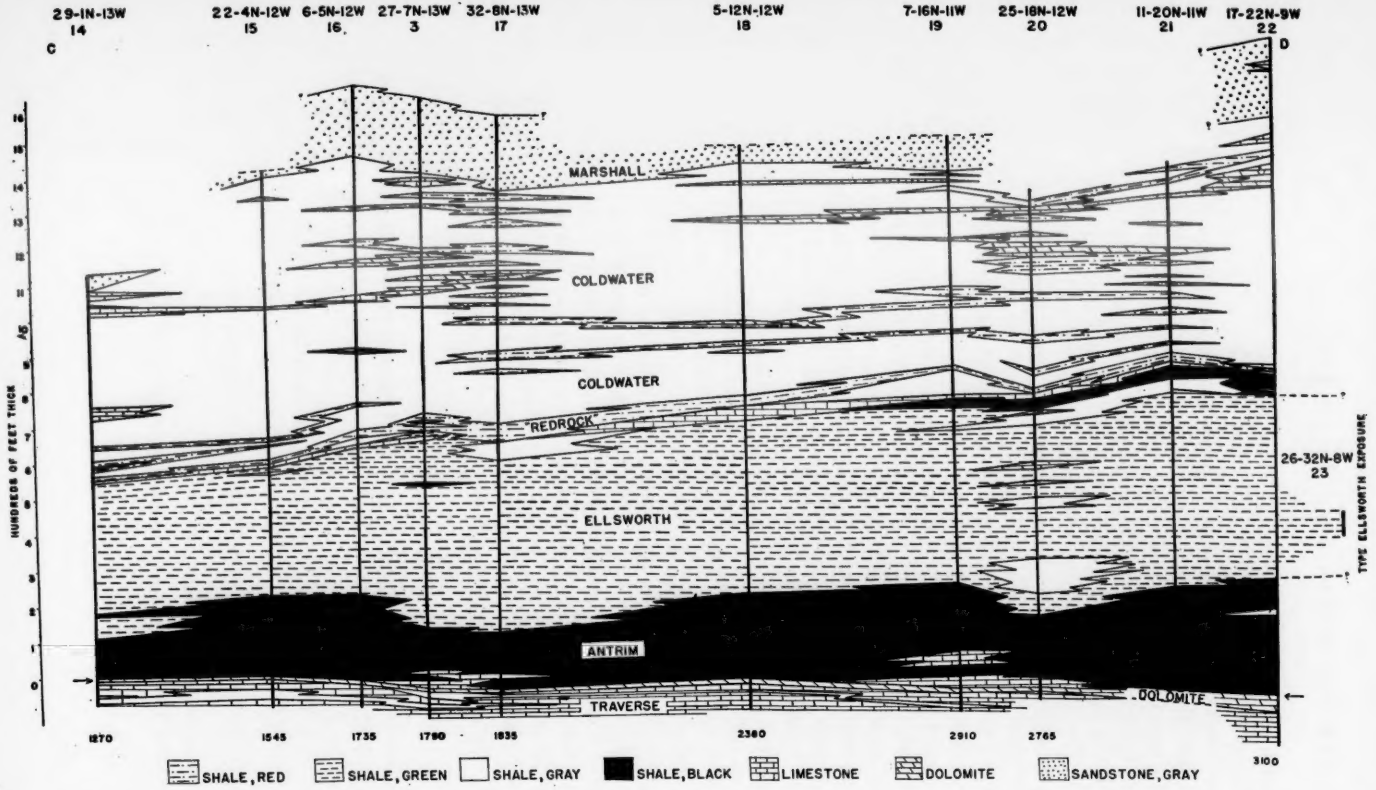

FIG. 2.—North-south cross section between points *D* and *C*, Antrim and Allegan counties, respectively. Lenticular reconstruction and correlations are mostly imaginative but represent what writer believes to be most logical interpretation. Columns were matched by vertical shifting so as to show best the stratigraphic relations. No datum plane was used; hence, structure is mostly flattened out. Elevation of dolomite (indicated by arrow) in relation to sea-level, is given at bottom of each column.

LOCATION OF WELLS

No.	*Permit*	*County*	*Sec.*	*Twp.*	*R.*	*Name of Well*	*Company*	*Elevation, Feet*
14	4639	Allegan	29	1 N.	13 W.	Clair 1	Flanigan	770.7
15	4723	Allegan	22	4 N.	12 W.	J. Dologewski 1	Lonoran Petr.	698.4
16	6340	Kent	6	5 N.	12 W.	H. B. Moorman 1	Majestic Oil	674.5
17	6632	Ottawa	32	8 N.	13 W.	J. H. Host 1	Welsh Oil	660.9
18	2545	Newago	5	12 N.	12 W.	W. Sawyer	C. W. Teeter	806.4
19	4460	Newago	7	16 N.	11 W.	Eichenberger 1	Mid-States Corp.	1028.
20	4424	Lake	25	18 N.	12 W.	K. W. Rice 1	Cherry Valley Drill	987.7
21	124	Lake	11	20 N.	11 W.	W. Kellogg 1	Fred J. Estes	1220.
22	4584	Wexford	17	22 N.	9 W.	Fee 1	G. H. Schrack	1337.

Lake. This description was made at the same outcrop as Douglass found.

In 1933, Newcombe[13] proposed the name Ellsworth for these shales and named the exposure 1½ miles south of Ellsworth, in the Petoskey Portland Cement Company quarry, where there is a ledge of 30–40 feet of greenish gray shale, as the type section. This location is in Sec. 26, T. 32 N., R. 8 W., Banks Township, Antrim County. According to Newcombe the Ellsworth is probably lower Mississippian in age, nearly equivalent to the Bedford shale of Ohio. Both Ehlers[14] and Bishop[15] believe that possibly the major break between the Devonian and Mississippian did not occur within this shale series. A correlation of this partial section with the entire section in the log of the first well at the south is indicated on Figure 2, Location 23, and on the index map of Michigan (Fig. 3).

Lithology.—The Ellsworth shale is gray-green or gray shale with many red shale, limestone, and dolomite lenses, which make up, however, a small part of the formation. It is soft to medium-hard and somewhat clay-like.

Vertical and horizontal distribution.—The total thickness of the strata has been estimated by Newcombe[16] to be between 500 and 600 feet in the western part of the state. In the wells studied by the writer, the thickness ranged from 400 to 500 feet. The formation as shown in Figures 1 and 3 is in the lower part equivalent to the upper beds of the Antrim, and in the upper part equivalent to the lower beds of the Coldwater. The term equivalent is used here to indicate thickness of sedimentation, not to indicate time intervals. Lenses of "Ellsworth type" occur commonly throughout the Antrim and Coldwater shales.

"BEREA" SANDSTONE

Type locality.—The Berea sandstone has nowhere been observed in outcrop in Michigan but a sandstone of "Berea type" has been traced in well cuttings along the eastern side of the state. It has been correlated with outcrops in Ohio, West Virginia, and Pennsylvania. The type locality is Berea, Cuyahoga County, Ohio. A similar sandstone which was thought for some time to be correlative with the Berea was called, in Michigan, the Richmondville sandstone and it

[13] Newcombe, *op. cit.*, p. 49.

[14] G. M. Ehlers, oral communication.

[15] M. S. Bishop, "Isopachous Studies of Ellsworth to Traverse Limestone Section of Southwestern Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 12 (December, 1940), p. 2153.

[16] R. B. Newcombe, *op. cit.*

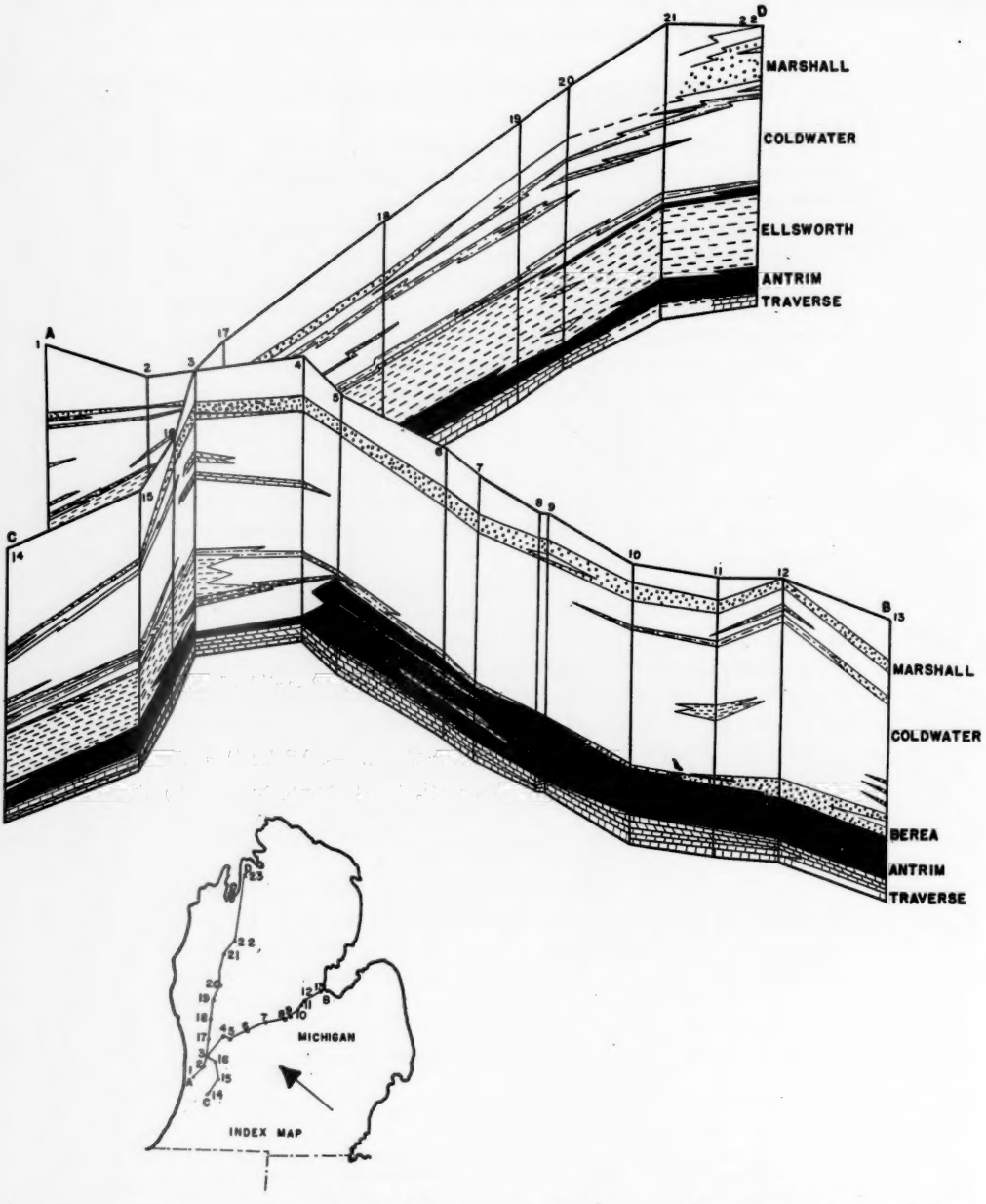

FIG. 3.—Composite correlation diagram of cross sections shown in Figures 1 and 2. Arrow of index map indicates position in which observer is viewing diagram. Index map of Michigan shows location of wells studied and charted in cross sections.

was said by Wright[17] to crop out at Richmondville, on Lake Huron. Later this was found to be a sandstone member in the lower Coldwater. Rominger[18] first identified 92 feet of the "Berea" in a well dug at the Ann Arbor Courthouse in 1871. Lane[19] interpreted 120 feet in a well dug on the campus of the University of Michigan in 1899, as "Berea," although only 15 feet of this was actually sandstone.

Lithology.—The "Berea" of Michigan is fine-grained, micaceous sandstone. The color is either gray or yellow or brown depending on the amount of disseminated pyrite grains in it and the amount of weathering. The quartz grains are angular and uniform in size. Gray shale commonly separates the sandstone layers. The "Berea" formed the third salt horizon in early geologic reports of the state.[20] The salt wells of Tawas, Oscoda and Huron obtained their salt from it.

Relation to Antrim, Bedford, and Sunbury formations.—In the area where the "Berea" is found, it ordinarily lies on the Antrim shale. A thin gray shale in places underlying the "Berea" has been called the Bedford shale by some geologists in the region but by others it has been included in the Antrim formation. A black or dark gray, pyritiferous shale that rests directly on the "Berea" has been called the Sunbury and in the eastern counties forms a mappable unit. In western Michigan it occurs only here and there as lenses within the Ellsworth. Correlation of these shales with the type formations after which they have been provisionally named has not been confirmed by paleontologic study.

Horizontal and vertical distribution.—The "Berea" has been found only in the eastern counties, and is best developed in the Thumb region. It thins in short distances westward and disappears along the line of section in Gratiot County (Fig. 1). It ranges in thickness from 10 to 150 feet.

COLDWATER SHALE

Type locality.—The Coldwater shale was named in 1893 by Lane[21] for outcrops in Branch County, along the Coldwater River. Outcrops are also found in Hillsdale County.

Lithology.—Lane stated that the Coldwater shale "consisted of light colored, greenish or bluish, sometimes darker, shales, growing

[17] C. E. Wright, *op. cit.*, p. 21.

[18] *Ibid.*, p. 23.

[19] I. C. Russell and F. Leverett, "Ann Arbor, Michigan," *U. S. Geol. Survey Atlas Folio 155* (1907), p. 4.

[20] A. C. Lane as reported by M. E. Wadsworth, *Michigan Geol. Survey Rept.*, Vol. V., Pt. 2 (1881–93), p. 20.

[21] A. C. Lane, *op. cit.*, p. 19.

sandier toward the top and gradually passing into the Marshall . . . may have occasional bands of limestone." More recent studies have noted the existence of several distinctive layers or lenses. The "Red-rock" or red shale of the formation, in the western part of the state is found at or near the base. This bed is extremely calcareous and changes in some localities into shaly limestone.[22] Hale[23] describes this layer as being "a fossiliferous limestone with some red shale; several very fossiliferous zones rich in crinoids, ostracods, and bryozoans with some brachiopods, gastropods, cephalopods, and pelecypods occur locally." In Kent and Ottawa counties, the Red Rock is underlain by a thin layer of limestone that contains oölites. Lenses of limestone, dolomite, and red and green shale are common throughout the Coldwater formation. On the east side of the state, there are several lenses of sandstone of the same texture and color as that of the "Berea" formation below.

Lane, upon naming the Coldwater formation, placed it in Winchell's Huron group, which Winchell, in 1861, placed in the Mississippian and designated all strata lying between the top of the Traverse limestone and the bottom of the Marshall sandstone as belonging to it.

Relation to underlying formations.—The bottom of the Coldwater rests on the black Sunbury shale, if present, and on the "Berea" (well 9) sandstone in the eastern counties, and mostly on the Ellsworth shale in the western counties.

Horizontal and vertical distribution.—According to Lane[24] the vertical limits of the Coldwater shale were set at the top, by the brine-bearing sandstone, the Marshall, and at the bottom, by the brine-bearing sandstone of Port Arthur and Oscoda, the "Berea." The horizontal distribution is state-wide. It ranges in thickness from approximately 700 feet in Allegan County to 1,000 feet in the center of the basin.

CORRELATIONS

In Figure 3, the composite correlation diagram, an attempt has been made to show, in three dimensions, the position of the wells studied and the relation of the strata to one another. The conception of tabular formations of wide extent with simple sequent stratigraphic relations must be altered to one in which several type lithologies are found in many interfingering and separate lenses. Altogether the lenses build up a shale series of uniform thickness (approximately 1,500 feet

[22] R. B. Newcombe, *op. cit.*, p. 54.

[23] L. Hale, "Study of Sedimentation and Stratigraphy of Lower Mississippian in Western Michigan," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (April, 1941), pp. 713–23.

[24] A. C. Lane, *op. cit.*, p. 20.

thick) but the separate units, each dominantly of an individual lithology, have interfingering lateral relations to one another. The great mass of gray shales, dominantly of Coldwater type, is entirely younger than the Antrim but the Ellsworth must be considered in part equivalent to the lower part of the Coldwater of the eastern counties, and in part equivalent to the upper part of the Antrim, also of the eastern counties. A large body of gray shale of "Coldwater type," in Kent County, seems equivalent to the upper part of the Antrim and actually below some Ellsworth type beds, but equivalent to other parts of the Ellsworth.

The problems of source, sedimentary environment, type, and growth of deposits are not discussed here because of the limitations of the sections under study.

Acknowledgments.—The writer is indebted to G. M. Ehlers, of the University of Michigan and Jed B. Maebius, of the Gulf Refining Company, Saginaw, Michigan, for critical reading of the manuscript and to the latter also for the loan of the well cuttings studied. The writer also wishes to thank A. J. Eardley, of the University of Michigan, for many helpful suggestions on the preparation of the cross sections and the interpretation of the stratigraphic relationships involved.

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GEOLOGICAL NOTES

FOSSILIFEROUS LOCALITIES OF MIDWAY GROUP IN LOUISIANA[1]

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University, Louisiana

The writers since the summer of 1939 have been engaged by the Louisiana Geological Survey in collecting and studying the lower Eocene molluscan fauna of Louisiana under the direction of H. N. Fisk. Collections from several localities (Fig. 1) in DeSoto, Sabine, and

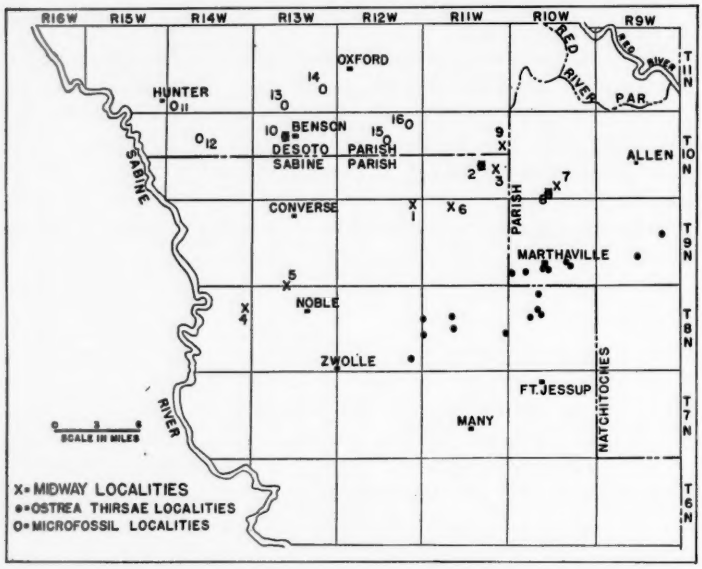

FIG. 1.—Index map of parts of DeSoto, Sabine, and Natchitoches parishes, Louisiana, showing location of fossiliferous Midway localities and *Ostrea thirsae* localities.

Natchitoches parishes contain a molluscan fauna comparable with the upper Midway faunas of Alabama and Texas. The only previous mention of the age and occurrence of a molluscan fauna within the area of these localities was by Harris,[3] who in reference to fossils from Sec. 2,

[1] Manuscript received, October 4, 1940. Published by permission of the Louisiana Geological Survey.

[2] Louisiana State University.

[3] G. D. Harris, "The Cretaceous and Lower Eocene Faunas of Louisiana, a Preliminary Report on the Geology of Louisiana," *Louisiana Geol. Survey Spec. Rept. 6* (1899), p. 306.

T. 9 N., R. 12 W., stated, "the last mentioned locality may be Midway." In his text, however, Harris placed the locality in the post-Midway "Lignitic stage." Subsequent workers have also considered the Eocene sediments within the area of these localities to be post-Midway and have referred these sediments to the Sabine (Wilcox) group.

In 1934 Howe and Garrett[4] divided the Sabine group into the Wilcox and Mansfield (lower) sub-groups and pointed out that the basal Wilcox of Louisiana, as of Alabama, is characterized by beds containing *Ostrea thirsae* (Gabb). In Louisiana this fossil, which characterizes the Nanafalia formation of Alabama, has been reported in abundance only from beds at Marthaville, Natchitoches Parish. The writers visited and collected from eighteen additional *Ostrea thirsae* localities between the Red River and Sabine River flood plains. These localities, shown on the index map, comprise a zone traceable from 8 miles east of Marthaville to 5 miles east of Zwolle, Sabine Parish, a distance of 19 miles. The establishment of this zone affords a much firmer basis for the correlation, proposed by Veatch[5] and Howe and Garrett,[6] of the beds at Marthaville with the Nanafalia formation.

The basal Wilcox of Texas is also the equivalent of the *Ostrea thirsae* zone of Louisiana. The writers have collected from three localities in this zone specimens of another oyster, *Ostrea multilirata* Conrad (*fasex* Gardner),[7] a species which according to Plummer occurs in the Caldwell Knob member of the Seguin formation, the basal Wilcox formation of Texas. Plummer[8] states:

> The Caldwell Knob member consists of a layer of oyster shells varying from a few inches to several feet in thickness, the average thickness being about one foot. The oysters, in most places *Ostrea multilirata* Conrad, lie in a matrix of calcareous silt which in most places is cemented into a hard sandy limestone. The bed has been traced by Miss Gardner from a point near Brazos River in Milam County to the Rio Grande Valley and has been identified on the Guerrero structure near Guerrero in Mexico. . . . The type locality of this member is Caldwell Knob located 10 miles north of Bastrop and about 2 miles south of Colorado River in Bastrop County, where the oyster *Ostrea multilirata* Conrad var. *duvali* Gardner is abundant.

[4] H. V. Howe and J. B. Garrett, Jr., "Louisiana Sabine Eocene Ostracoda," *Louisiana Geol. Survey Bull. 4* (1934), pp. 1–14.

[5] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana," *Geol. Survey Louisiana Report of 1905*, Bull. 4 (1906), p. 27.

[6] Howe and Garrett, *op. cit.*, p. 12.

[7] For a discussion of this species see H. V. Howe, " 'The Many Salt Dome,' Sabine Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (1925), p. 170, and Julia Gardner, "The Restoration of *Ostrea multilirata* Conrad, 1857," *Washington Acad. Sci. Jour.*, Vol. 16 (1926), pp. 513–14.

[8] F. B. Plummer, "Cenozoic Systems in Texas," *Univ. Texas Bull. 3232*, Pt. 3 (1933), p. 577.

The extension of the *Ostrea multilirata* zone into Louisiana as a part of the *Ostrea thirsae* zone forms the connecting link between the lower Wilcox of Alabama and of Texas.

The fossiliferous Midway localities, shown on Figure 1, are 5–15 miles north of the *Ostrea thirsae* zone and occur in sediments lithologically similar to the overlying fossiliferous Sabine (Wilcox).

Description of Midway Localities

Sabine Parish

Locality 1. Ravine in approximate center of NW. ¼ of Sec. 1, T. 9 N., R. 12 W. Locality is about one-third mile east of locality cited by Harris. Fossils occur in septarian calcareous concretions. Elevation, 270 feet

Locality 2. Road-cut on west side of Louisiana Highway 180 about 2½ miles northeast of Pleasant Hill in SW. ¼, SW. ¼ of Sec. 23, T. 10 N., R. 11 W. Fossils occur in calcareous concretions in gray calcareous clays. Foraminifera present in clays. Elevation, 323 feet

Locality 3. Extreme southwest corner of Sec. 24, T. 10 N., R. 11 W. on Walker's place. Fossils occur in septarian concretions on the hill tops and at break of slopes

Locality 4. Road-cut in center of Sec. 12, T. 8 N., R. 14 W. Numerous specimens of *Anomia* sp. collected from glauconitic ferruginous concretions. Elevation, 220 feet.

Locality 5. Road-cut along U. S. Highway 171 about ½ mile south of San Patricio Bayou in south center of Sec. 33, T. 9 N., R. 13 W. Only a few indeterminate specimens collected from calcareous siltstone. Elevation, 205 feet

Locality 6. Road-cut along Louisiana Highway 1 in the NW. ¼, SW. ¼ of Sec. 4, T. 9 N., R. 11 W. Only a few specimens found in ferruginous concretionary layer underlain by grayish brown silty clay. Elevation, 370 feet

Natchitoches Parish

Locality 7. Cultivated field north of farmhouse in NE. ¼, NW. ¼ of Sec. 34, T. 10 N., R. 10 W., on Louisiana Highway 404, about 4½ miles south of Ajax. Farmhouse is on east side of road. Fossils occur in yellowish brown septarian calcareous siltstone concretions. Elevation, 190 feet

Locality 8. Road-cut in NE. ¼, SE. ¼ of Sec. 33, T. 10 N., R. 10 W., along dirt road leading west from Louisiana Highway 404. Fossils collected from yellowish brown sandy silts overlain by calcareous siltstone concretions. These sediments crop out on road just east of bridge over Rocks Creek. Elevation, 170 feet. Foraminifera present

DeSoto Parish

Locality 9. On local road leading north from Louisiana Highway 180. Locality is in SW. ¼, NE. ¼ of Sec. 13, T. 10 N., R. 11 W. Fossils occur in calcareous siltstone concretions. Elevation, 280 feet

Locality 10. Road-cut on Louisiana Highway 745 in SW. ¼, NE. ¼ of Sec. 9, T. 10 N., R. 13 W. Fossil casts collected from chocolate-brown clays. Elevation, 240 feet. Foraminifera present

At localities 11–16 only *Foraminifera* were collected. Grover Murray, Jr., of the Louisiana Geological Survey, is making a study of these fossils

The large number of species common to the fauna from Louisiana (Table I) and to the faunas of the Wills Point and Naheola formations establishes the upper Midway age of the fauna from Louisiana. In particular this fauna shows a close relationship to that at the type locality of the Kerens member of the Wills Point formation.

Of the species previously unreported from formations older than the Wilcox only *Fusus bellanus* was restricted to any one formation. This species has been reported only from the Tuscahoma locality at Bells

Landing, Alabama. *Levifusus pagoda* has been reported from the Wilcox and Claiborne, and *Calyptraphorus trinodiferus* occurs throughout the Wilcox of Alabama and the upper and middle Wilcox of Texas.

TABLE I

CHECK LIST OF LOUISIANA MIDWAY EOCENE MOLLUSCA

	LOUISIANA Midway Localities										TEXAS				ALABAMA			TENN.	
												Midway				Midway			
	1	2	3	4	5	6	7	8	9	10	Wilcox	Wills Point		Kincaid	Wilcox	Nanafalia	Clayton	Midway	Undiff.
PELECYPODA																			
Nucula ovula Lea								X			X				X	X			
Leda sp.	X	X	X				X	X											
Yoldia kindlei Harris		X						X											X
Pinna gardnerae Claypool*		X					X	X				X							
Anomia sp.				X		X													
Modiolus sp.							X												
Venericardia sp.	X	X	X				X	X											
Lucina sp.	X									X									
Cardium sp.			X				X												
Tellina sp. cf. T. estellensis Aldrich	X	X	X				X				X	X							
Corbula sp.	X	X					X	X											
Martesia sp.		X						X											
GASTROPODA																			
Fissurella ? sp.							X	X											
Epitonium sp.	X		X				X												
Ampullina alabamiensis (Whitfield)							X				X	X		X	X	X			
Polinices harrisii Gardner	X	X	X		X			X	X										
Sinum sp.							X												
Turritella aldrichi Bowles	?	X						X								X	X		
Turritella sp. A	?								X										
Turritella sp. B								X	X										
Calyptraphorus aldrichi Gardner	X	X					X	X						X		X			
Calyptraphorus sp. cf. C. trinodiferus Conrad			X					X											
Galeodea ? sp.							X												
Priscofieus juvenis (Whitfield)	X						X				X	X			X	X			
Mitrella sp.								X											
Fusus bellanus Harris								X							X				
Levifusus pagoda (Heilprin)		X						X			X				X				
Levifusus pagoda var. Harris								X								X			
Falsifusus ottonis (Aldrich)var.	X											X		X		X			
Athleta petrosa (Conrad) var.	X	X	X				X	X	X										
Turris kerenensis Claypool*								X				X				?			
Orthosurcula persa (Whitfield) var.	X	X	X				X	X				X							
Orthosurcula longipersa(Harris)	X	?	X				X	X	X			X				X			
Orthosurcula sp. aff. O. adeona (Whitfield)							X	X											
Bullinella sp.								X											
Cornulina sp.								X											

* Names used by C. B. Claypool, "The Wilcox of Central Texas," abstract of thesis (Univ. Illinois), Urbana, Illinois (1933), p. 8. The writers wish to thank Professor A. H. Sutton of the University of Illinois for the loan of Claypool's specimens from the type locality of the Kerens member of the Midway Wills Point formation of Texas.

Tellina sp. cf. *T. estellensis* occurs in the Solomon Creek[9] member of the Wilcox Seguin formation and the Kerens member of the Midway Wills Point formation.

[9] The writers are indebted to Miss Julia Gardner of the United States Geological Survey for the loan of material from Solomon Creek and also for many kind and helpful suggestions.

MIDWAY MICROFAUNA OF NORTHWESTERN LOUISIANA[1]

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Surface samples collected by the writer and fellow graduate students of Louisiana State University during geological investigations for the Louisiana Geological Survey in De Soto, Natchitoches, Red River, and Sabine parishes in 1939 and 1940 have yielded interesting microfaunas that suggest Midway relationships. Of more than one hundred samples collected for microscopic studies, only ten have yielded faunas of any size. These ten all lie within the outcrop area of Howe and Garrett's Mansfield sub-group of the Sabine group and of Moody's Wilcox group.

The ten localities have yielded a total of approximately seventy-five species of Foraminifera, ten species of Ostracoda, and a single bryozoan. Of the Ostracoda, *Cythereis prestwichiana* Jones and Sherborn and *Cytheromorpha scrobiculata* Alexander were the only species that could be identified. The other genera represented were *Cytherella*, *Cytheridea* (*Clithrocytheridea*), *Cytherideis*, *Bythocypris* (?), *Eucytherura*, and *Argilloecia* (?). The single bryozoan was too poorly preserved to permit indentification.

The foraminiferal determinations are based on the works of Plummer,[3] Cushman,[4] Cushman and Ponton,[5] Cushman and Garrett,[6] Cushman and Waters,[7] and Jennings.[8] Topotype specimens from the

[1] Manuscript received, October 4, 1940; additions received, March 8, 1941.

[2] Louisiana Geological Survey, Louisiana State University.

[3] Helen Jeanne Plummer, "Foraminifera of the Midway Formation in Texas," *Univ. Texas Bull. 2644* (1926). 206 pp.
———, "Foraminiferal Evidence of the Midway-Wilcox Contact in Texas," *Univ. Texas Bull. 3201* (1932), pp. 51–68.
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[4] J. A. Cushman, "A Monograph of the Foraminiferal Family Verneuilinidae," *Cushman Lab. Foram. Research Contrib.*, Spec. Pub. 7 (1937). 157 pp.
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[5] J. A. Cushman and G. M. Ponton, "An Eocene Foraminiferal Fauna of Wilcox Age from Alabama," *ibid.*, Vol. 8, Pt. 3 (1932), pp. 51–72.

[6] J. A. Cushman and J. B. Garrett, "Eocene Foraminifera of Wilcox Age from Woods Bluff, Alabama," *ibid.*, Vol. 15, Pt. 4 (1939), pp. 77–89.

[7] J. A. Cushman and J. A. Waters, "Some Arenaceous Foraminifera from the Upper Cretaceous of Texas," *ibid.*, Vol. 2, Pt. 4 (1927), pp. 81–85.

[8] P. H. Jennings, "A Microfauna from the Monmouth and Basal Rancocas Groups of New Jersey," *Bull. Amer. Paleontology*, Vol. 23, No. 78 (1936), pp. 159–234.

H. V. Howe collection, slides of the Alabama and Texas Midway faunas, and of the Alabama Wilcox faunas have been available for comparative studies.

Approximately half of the foraminiferal species could be identified. The most important of these species are here listed. Those marked with an asterisk have been compared with topotype specimens. The others have been compared with specimens from the Alabama or Texas Midway sediments.

**Haplophragmoides canariensis* (d'Orbigny)
Ammobaculites expansus Plummer
A. midwayensis Plummer
**Textularia plummerae* Lalicker
**T. carinata* d'Orbigny var. *expansa* Plummer
**Clavulinoides midwayensis* Cushman
**Cristellaria subaculeata* Cushman var. *tuberculata* Plummer
**Cristellaria turbinata* Plummer
**Cristellaria* sp. cf. *C. midwayensis* Plummer
Nonionella turgida (Williamson)
Bullopora chapmani (Plummer)
B. laevis (Sollas)
Cf. *Gümbelina midwayensis* Cushman
Siphogeneroides eleganta (Plummer)
Bolivina midwayensis Cushman
**Loxostoma applinae* (Plummer)
Angulogerina sp. cf. *A. wilcoxensis* (Cushman and Ponton)
Discorbis midwayensis Cushman
Discorbis sp. cf. *D. infrequens* Plummer
**Rotalia soldani* (d'Orbigny) var. *subangulata* Plummer
Coleites reticulosus (Plummer)
Siphonina sp. cf. *S. prima* Plummer
Globigerina compressa Plummer
**G. pseudo-bulloides* Plummer
**G. triloculinoides* Plummer
Anomalina sp. cf. *A. welleri* (Plummer)
**A. ammonoides* (Reuss) var. *acuta* Plummer
**A.* sp. cf. *A. midwayensis* (Plummer)
**A. midwayensis* (Plummer) var. *trochoidea* Plummer

Among the additional species determined, the most common are: *Cristellaria rotulata* (Lamarck), *C. orbicularis* (d'Orbigny), *C.* sp. cf. *C. trigonata* Plummer, *Nonion* sp. cf. *N. wilcoxensis* Cushman and Ponton, *Pullenia quinqueloba* (Reuss), *Bolivina* sp. cf. *B. carinata* (Terquem), *Cibicides americanus* (Cushman) (several varieties), and *C.* sp. cf. *C. cultur* (Parker and Jones). Numerous unidentified species of *Spiroplectammina, Ammobaculites,* and *Haplophragmoides* are usually present and at some localities constitute the entire fauna. Other unidentified species belong to the genera *Trochammina, Textularia, Verneuilina, Gaudryina, Quinqueloculina, Masselina, Cristellaria, Globulina, Nonion, Operculinoides* (?), *Uvigerina, Angulogerina, Globorotalia, Planorbulina* (?) and, or *Planorbulinella* (?). Forms believed to be *Adhaerentia midwayensis* Plummer were present at one locality.

The accompanying check list (Table I) displays the fauna from the four most fossiliferous localities. The reported occurrences of the identi-

TABLE I

CHECK LIST OF SPECIES OF FORAMINIFERA AND OSTRACODA FROM UPPER MIDWAY SEDIMENTS OF LOUISIANA

	Midway Group								*Wilcox Group*			
	*Texas**		*Louisiana†*									
	Upper	Lower	Map No. 8 GM Loc. 258	Map No. 10 GM Loc. 124	Map No. 12 GM Loc. 118	GM Loc. 198	Mississippi Upper Midway‡	Alabama§	Alabama‖			
Foraminifera												
Haplophragmoides canariensis (d'Orbigny)	x	x		x	x							
Ammobaculites expansus Plummer	x		x	x	x							
A. midwayensis Plummer	x		x	x	x		x	x				
Textularia plummerae Lalicker	x				x			x	x			
T. carinata d'Orbigny var. *expansa* Plummer	x				x							
Clavulinoides midwayensis Cushman	x	x	x		x			x				
Cristellaria subaculeata Cushman var. *tuberculata* Plummer	x				x	x						
Cristellaria turbinata Plummer	x					x		x				
Cristellaria sp. cf. *C. midwayensis* Plummer	x	x	x	x		x	x	x	x			
Nonionella turgida (Williamson)	x				x	x			x			
Bullopora chapmani (Plummer)	x	x						x				
B. laevis (Sollas)	x	x						x				
Cf. *Gumbelina midwayensis* Cushman					x			x				
Siphogeneroides eleganta (Plummer)	x	x			x			x				
Bolivina midwayensis Cushman					x			x				
Loxostoma applinae (Plummer)	x				x		x	x				
Angulogerina sp. cf. *A. wilcoxensis* (Cushman and Ponton)					x	x			x			
Discorbis midwayensis Cushman					x			x				
Discorbis sp. cf. *D. infrequens* Plummer	x		x									
Rotalia soldani (d'Orbigny) var. *subangulata* Plummer	x	x			x	x						
Coleites reticulosus (Plummer)	x					x		x	x			
Siphonina sp. cf. *S. prima* Plummer	x	x		x	x		x	x				
Globigerina compressa Plummer	x					x	x		x			
G. pseudo-bulloides Plummer	x	x	x	x	x	x		x				
G. triloculinoides Plummer	x	x	x	x	x	x	x	x	x			
Anomalina sp. cf. *A. welleri* (Plummer)	x		x	x					x			
A. ammonoides (Reuss) var. *acuta* Plummer	x	x				x		x	x			
A. sp. cf. *A. midwayensis* (Plummer)	x	x	x	x	x		x	x				
A. midwayensis (Plummer) var. *trochoidea* Plummer	x	x	x		x			x				
Ostracoda												
Cythereis prestwichiana Jones and Sherborn	x	x				x			x			
Cytheromorpha scrobiculata Alexander	x	x				x						

fied species from the lower Eocene sediments of Alabama, Mississippi, and Texas are indicated.

The microfauna, as does the macrofauna (see Barry and LeBlanc), indicates an upper Midway age for the sediments stratigraphically below the *Ostrea thirsae* zone[9] in Louisiana and above the Midway black shale unit. The upper Midway sediments are exposed in northern Sabine Parish, in northern Natchitoches Parish, in western Red River Parish, in western Bienville Parish, in southern Caddo Parish, in all of De Soto Parish, and in parts of Panola and Shelby counties, Texas. No field work has been done yet in Bossier Parish to the north, where the upper Midway sediments also undoubtedly crop out.

A detailed report by the writer on the zonation, division, and correlation of the lower Eocene sediments of this area will appear in a future bulletin of the Louisiana Geological Survey on the geology of De Soto and Red River parishes, Louisiana.

The localities from which the best microfaunas have been obtained are here listed. They are indicated on the regional map (p. 734) by a circle.[10]

LOCALITIES OF MICROFAUNA

Map Number

2. GM Loc. 163 (RJL Loc. 2).—Road-cut on west side of Louisiana Highway 180 about 2½ miles northeast of Pleasant Hill in SW. ¼, SW. ¼ of Sec. 23, T. 10 N., R. 11 W., Sabine Parish. Fossils occur in large calcareous concretions in gray calcareous clays. Elevation, 323 feet

[9] The rarity of *Foraminifera* in Wilcox sediments correlative with, and immediately overlying, the *Ostrea thirsae* zone in Louisiana, unfortunately prevents a detailed comparison of foraminiferal faunas from these and underlying strata. However, Howe and Garrett in 1934 have confirmed by ostracodal studies that sediments correlative with the Nanafalia of Alabama are present in the Louisiana lower Eocene section. Currently, the representatives of the Coal Bluff and Ackerman strata of Alabama and Mississippi are undetermined in the Louisiana section. They may be represented by outcrops in the vicinity of Noble and Belmont, Sabine Parish, Louisiana, but a more exact determination must await additional detailed studies. Consequently, any attempt to draw an exact Midway-Wilcox contact in this area is unsatisfactory.

[10] Rufus J. LeBlanc and John O. Barry, "Fossiliferous Localities of Midway Group in Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (April, 1941), pp. 734–37, Fig. 1.

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* Helen Jeanne Plummer, "Foraminifera of the Midway Formation in Texas," *Univ. Texas Bull. 2644* (1926). 206 pp.
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† Compare: C. I. Alexander, "Stratigraphy of the Midway Group (Eocene) of Southwestern Arkansas and Northwestern Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (1935), pp. 696–99.

‡ W. O. George and H. X. Bay, "Subsurface Data on Covington County, Mississippi," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 10 (1935), pp. 1148–61.

§ J. A. Cushman, "Midway Foraminifera from Alabama," *Cushman Lab. Foram. Research Contrib.*, Vol. 16, Pt. 3 (1940), pp. 51–73.

‖ J. A. Cushman and G. M. Ponton, *op. cit.* (1932).
J. A. Cushman and J. B. Garrett, *op. cit.* (1939).
L. D. Toulmin, "The Salt Mountain Limestone of Alabama," *Alabama Geol. Survey Bull. 46* (1940). 126 pp.

8. RJL Loc. 9 (GM Loc. 258).—Road-cut in NE. ¼, SE. ¼ of Sec. 33, T. 10 N., R. 10 W., Natchitoches Parish, along dirt road leading west from Louisiana Highway 404. Fossils collected from yellowish brown sandy silts overlain by calcareous siltstone concretions. Sediments crop out on road just east of bridge over Rocks Creek. Elevation, 170 feet
10. GM Loc. 124 (RJL Loc. 10).—Road-cut about ½ mile west of U. S. Highway 171 on north side of Louisiana Highway 745 in SW. ¼, NE. ¼ of Sec. 9, T. 10 N., R. 13 W., De Soto Parish. Fossils collected from chocolate-brown clays. Elevation, 240 feet
11. GM Loc. 69.—30-foot water well in NE. ¼, SW. ¼ of Sec. 31, T. 11 N., R. 14 W., De Soto Parish. Sample from depth of 20 feet. Elevation at top of hole, 240 feet
12. GM Loc. 118.—Road-cut, 3.7 miles southeast of Hunter on south side of Hunter-Converse road in SW. ¼ of Sec. 9, T. 10 N., R. 15 W., De Soto Parish. Elevation, 260 feet
13. GM Loc. 164.—Road-cut on west side of U. S. Highway 171 about 0.7 mile south of Catuna in SW. ¼ of Sec. 33, T. 11 N., R. 13 W., De Soto Parish
14. GM Loc. 169.—Road-cut on north side of Oxford-Benson road near center of E. ½ of Sec. 26, T. 11 N., R. 13 W., De Soto Parish. Elevation, 270–275 feet
15. GM Loc. 175.—Road-cut on west side of local road from Pelican to Pleasant Hill in NE. ¼, NW. ¼ of Sec. 15, T. 10 N., R. 12 W., De Soto Parish. Elevation, 330 feet
16. GM Loc. 176.—15-foot borehole on east side of local road in southwest corner of Sec. 1, T. 10 N., R. 12 W., De Soto Parish. Elevation, top of hole, 360 feet. Depth of sample, 8 feet

Not on map. GM Loc. 198.—15-foot borehole on hillside on south side of Hunter-Converse Highway, 0.1 mile north of De Soto-Sabine Parish line in Sec. 16, T. 10 N., R. 14 W., De Soto Parish. Elevation, top of hole, 225 feet. Depth of samples, 9 and 13–13½ feet

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TENTATIVE CORRELATION CHART OF GULF COAST[1]

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The accompanying chart showing a tentative correlation of the stratigraphic units of the Gulf Coast was compiled for use in a course in subsurface correlation taught by the writers at Louisiana State University. The present chart represents a revision and expansion of an earlier one prepared by Paul Montgomery and used for the same purpose. When the chart was prepared the writers had no intention of publishing it, but at the suggestion of many who have seen it and due to the outside demand for copies they dare to publish it.

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[2] Assistant professor of economic geology, Louisiana State University.

[3] Assistant in geology, Louisiana State University.

They dare to publish it realizing that there are many unsolved problems in the stratigraphy of the region involved. The bibliography given herewith constitutes the published sources of information used in preparing the chart. Anyone familiar with this literature will realize that there are conflicts in usage of stratigraphic nomenclature in the several references. In instances of conflict the writers have chosen, for what seemed good reasons, the usage shown.

In addition to the published information cited the writers have discussed the problems of correlation with many individuals. These include members of the faculty in the department, geologists of the State Geological Survey of Louisiana and geologists of oil companies working in the Gulf Coast.

Many of the correlations shown are the result of these conversations and although it is impossible to give full credit in each instance the writers are no less grateful for the assistance. Without doubt there are individuals who have further data on some of these perplexing problems and it is hoped that they will suggest changes and additions. A chart of this type will improve only if there is constructive criticism from those with additional data. The writers will welcome such criticism.

The writers are indebted also to Stanley M. McDonald, geologist, Louisiana Geological Survey, for lettering the chart.

The numbers on the chart refer to references in the bibliography which are indicated by corresponding numbers.

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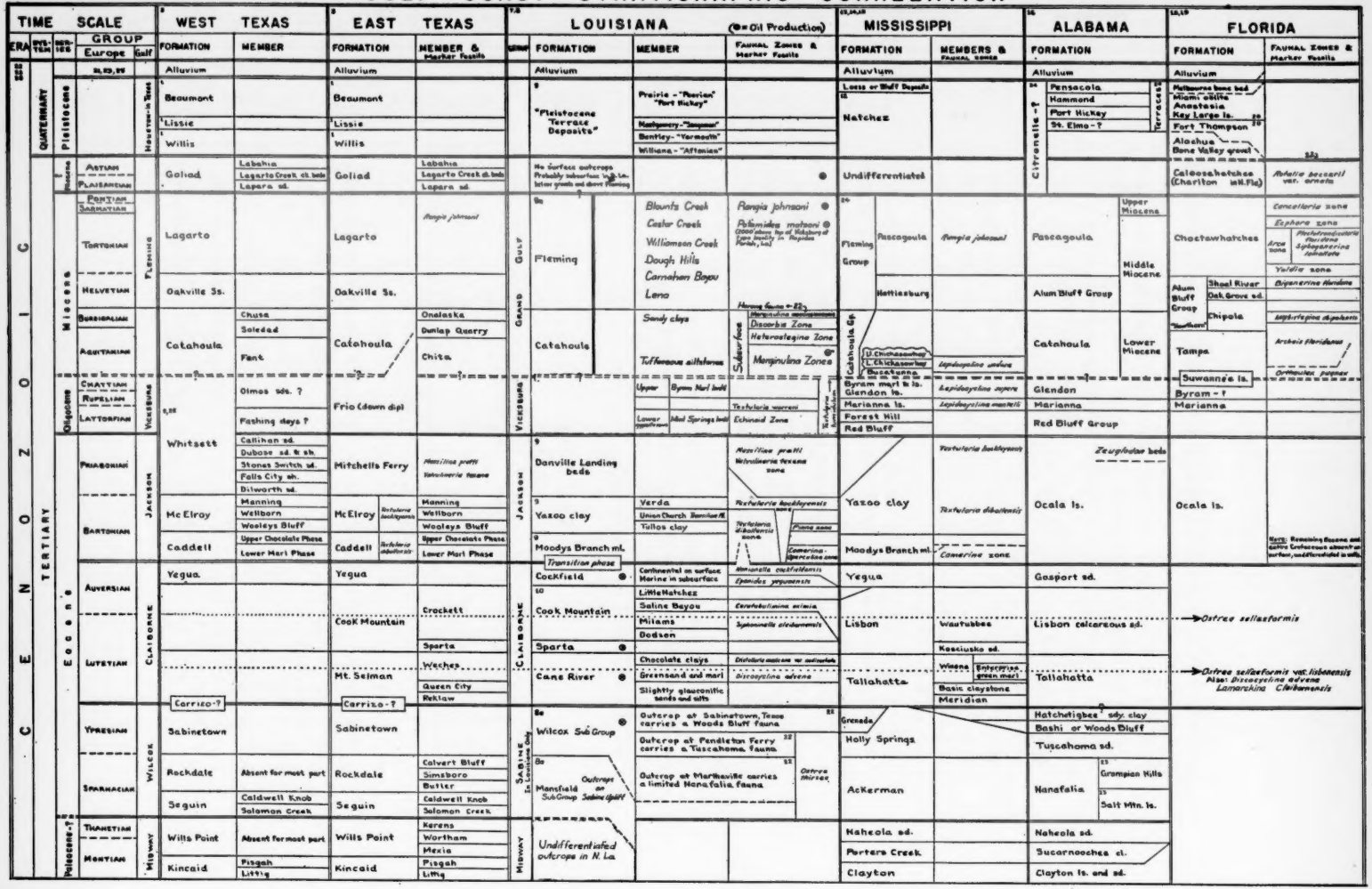
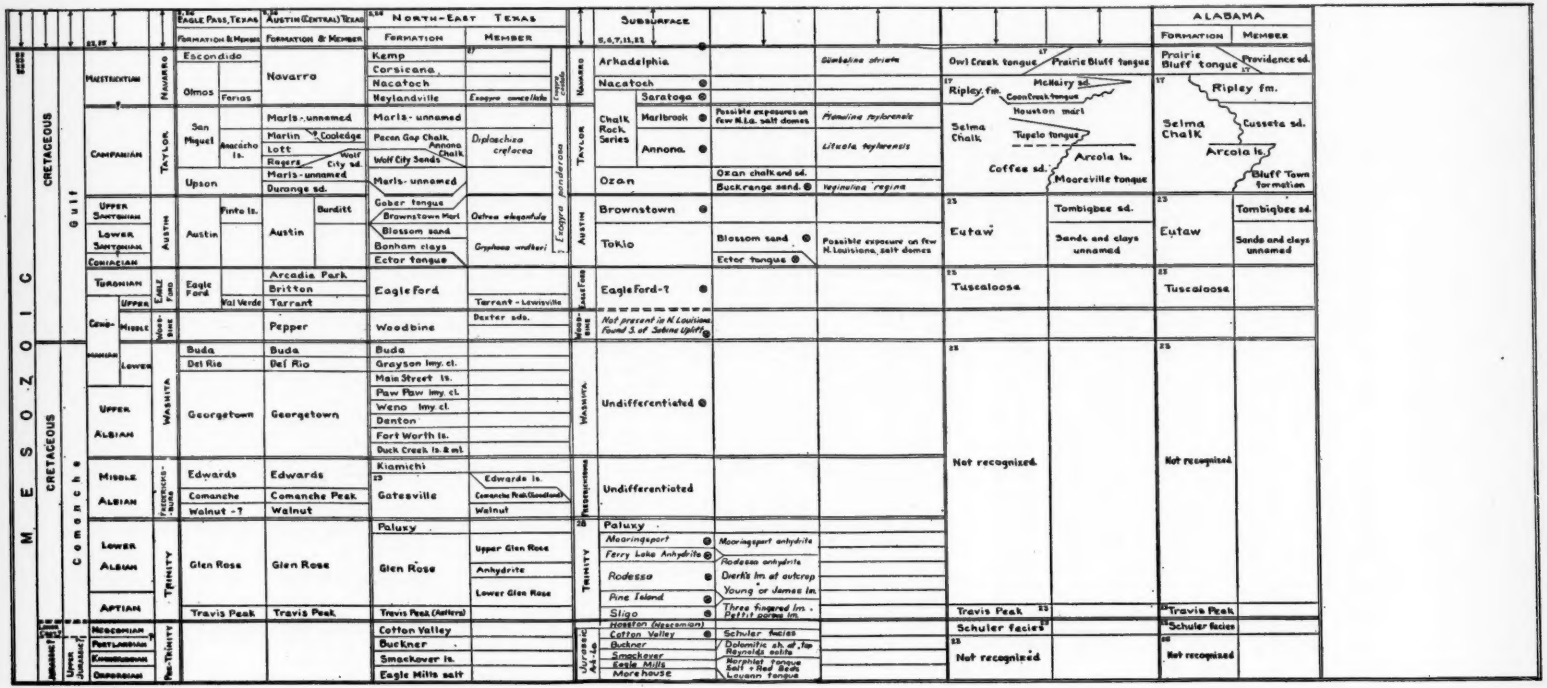
GULF COAST STRATIGRAPHIC CORRELATION




MESOZOIC
CRETACEOUS
Gulf
Comanche
CRETACEOUS
Jurassic
Upper Jurassic
Maestrichtian
Campanian
Upper Santonian
Lower Santonian
Coniacian
Turonian
Cenomanian
Upper
Middle
Lower
Upper Albian
Middle Albian
Lower Albian
Aptian
Neocomian
Portlandian
Kimmeridgian
Oxfordian
Navarro
Taylor
Austin
Eagle Ford
Woodbine
Washita
Fredericksburg
Trinity
Pre-Trinity
Escondido
Olmos
Ferias
San Miguel
Anacacho ls.
Upson
Austin
Pinto ls.
Burditt
Eagle Ford
Val Verde
Britton
Arcadia Park
Buda
Del Rio
Georgetown
Edwards
Comanche
Walnut - ?
Glen Rose
Travis Peak
Navarro
Corsicana
Nacatoch
Neylandville
Exogyra costata
Marls - unnamed
Martin
Lott
Rogers
Wolf City sd.
Cooledge
Upson
Durango sd.
Gober tongue
Brownstown Marl
Blossom sand
Bonham clays
Ector tongue
Exogyra ponderosa
Ostrea elegantula
Gryphaea vesicularis
Arcadia Park
Britton
Eagle Ford
Tarrant
Pepper
Woodbine
Dexter sds.
Buda
Del Rio
Grayson lmy. cl.
Main Street ls.
Paw Paw lmy. cl.
Weno lmy cl.
Denton
Fort Worth ls.
Duck Creek ls. & ml
Georgetown
Kiamichi
Edwards
Comanche Peak
Walnut
Gatesville
Edwards ls.
Comanche Peak (Goodland)
Walnut
Paluxy
Glen Rose
Upper Glen Rose
Anhydrite
Lower Glen Rose
Travis Peak (Hosston)
Cotton Valley
Buckner
Smackover ls.
Eagle Mills salt
Subsurface
Arkadelphia
Nacatoch
Saratoga
Chalk Rock Series
Marlbrook
Annona
Ozan
Brownstown
Tokio
Eagle Ford-?
Not present in N. Louisiana, found S. of Sabine Uplift
Undifferentiated
Paluxy
Mooringsport
Ferry Lake Anhydrite
Rodessa
Pine Island
Sligo
Hosston (Hosstonian)
Cotton Valley
Buckner
Smackover
Eagle Mills
Morehouse
Glauconitic strata
Planulina texanensis
Lituola texanensis
Vaginulina regina
Ozan chalk and sd.
Buckrange sand.
Possible exposures on few N.La. salt domes
Blossom sand
Ector tongue
Possible exposure on few N. Louisiana salt domes
Mooringsport anhydrite
Rodessa anhydrite
Overlies lm. at outcrop
Young or James lm.
Three fingered lm. - Pettit paleo lm.
Schuler facies
Dolomitic sh. at Top Reynolds salts
Morphlot tongue
Salt + Red Beds
Louann tongue
Not recognized
Owl Creek tongue
Prairie Bluff tongue
Ripley fm.
McNairy sd.
Coon Creek tongue
Houston marl
Tupelo tongue
Coffee sd.
Arcola ls.
Mooreville tongue
Selma Chalk
Eutaw
Tombigbee sd.
Sands and clays unnamed
Tuscaloosa
Travis Peak
Schuler facies
Not recognized
Prairie Bluff tongue
Providence sd.
Ripley fm.
Cusseta sd.
Arcola ls.
Bluff Town formation
Selma Chalk
Eutaw
Tombigbee sd.
Sands and clays unnamed
Tuscaloosa
Travis Peak
Schuler facies
Not recognized

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OLLA FIELD, LA SALLE PARISH, LOUISIANA[1]

S. A. PACKARD[2] AND H. R. KAMB[3]
Shreveport, Louisiana

The Olla field extends north and south along the common line of T. 10 N., R. 2 and 3 E., and into the extreme northeast corner of T. 9 N., R. 2 E., La Salle Parish, Louisiana. The Urania field is 4 miles west; the town of Olla, for which the field is named, is 3 miles northwest; and Jena, the Parish seat, is 10 miles southeast. The locality is on the north edge of what is commonly called the central Louisiana district.

The new field is notable as the first large producer of oil from sands below the top of the Eocene Wilcox group. Previous important Wilcox fields, for example, Urania and Eola, had found production only in the top sand member.

The discovery of oil at Urania in 1926 caused widespread shallow wildcatting in the surrounding area with nearly all tests penetrating less than 200 feet into the Wilcox. This activity provided sufficient subsurface control to outline favorable structure east and northeast of the old Urania field where, in the spring of 1939, after checking with reflection seismograph, the Arkansas Fuel Oil Company began a three-well exploration program of the Wilcox and deeper formations.

The first wildcat in Sec. 31, T. 12 N., R. 3 E., Caldwell Parish, was a failure and was abandoned in the Lower Cretaceous at 7,538 feet.

The second test, the Good Pine Lumber Company No. 1, center of the NW. $\frac{1}{4}$, NW. $\frac{1}{4}$ of Sec. 18, T. 10 N., R. 3 E., La Salle Parish, was a joint test with H. L. Hunt, the holder for several years of a large blanket lease on lumber-company acreage in the area, and led to the discovery of the Olla field. In December, 1939, shortly after commencing operations, a blow-out occurred while drilling at 3,050 feet. An electrical survey revealed probable gas saturation in a sand 735 feet below the top of the Wilcox, at 2,375 feet, and other sands of interest close above. Subsequently, the sand at 2,375 feet was called the Good Pine. While the joint well was continued to contract depth of 7,500 feet and eventually to 8,997 feet, H. L. Hunt drilled his Louisiana Central Lumber Company No. 9 as a west offset to explore the shallow showings. Oil- and gas-saturated sands were cored and, after failure to shut out gas and water in the Good Pine, this sand was plugged off and the well completed, April 2, 1940, as the field's first oil producer, flow-

[1] Manuscript received, February 14, 1941.

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[3] District geologist, Arkansas Fuel Oil Company.

ing 9 barrels of oil per hour through 7/32-inch choke from a sand at 2,263–2,288 feet. This initial producing sand was named the lower Central. It lies 600 feet below the top of the Wilcox. The deep test, the Good Pine No. 1, was later plugged back and also completed in the lower Central sand.

Ensuing development of the Olla field has shown that the productive sands and certain other adjacent beds within the Wilcox can be correlated throughout the field. This section, termed the Olla zone, is entered about 470 feet below the top of the Wilcox and averages 300 feet in thickness. Five producing oil and gas sands are known at present and have been named, in descending order, the upper Central, lower Central, Mathews, Cruse, and Good Pine. The position in the geologic column of the Olla zone and its sands and depths are illustrated in the type electrical log here presented (Fig. 1). Surface elevations vary from 111 to 185 feet.

The Olla zone is characterized by the presence of glauconitic and calcareous sands and marls suggesting that it is in part, at least, of shallow marine origin. The general continuity of the Olla sands throughout the field is further evidence of this although in places a sand may be shaly. No information is available providing certain correlation of the Olla zone with any recognized subdivision of the Wilcox.

The Olla field lies on a narrow, elongate north-south anticlinal ridge of small closure along the east side of what is here termed the Urania uplift. Superimposed along this ridge are one larger local closure and three minor closures as disclosed by present drilling, but the structural pattern is still incomplete.

Structure within the field appears to be irregular as mapped on a contour interval of 25 feet or less. This may be attributable to small faults of 20–30 feet displacement which are difficult to recognize and map, or to local thinning and thickening at the time of deposition. No major faulting is apparent.

Seventy-four oil wells and one gas well had been completed to November 25, 1940. Forty-four produce from the upper or lower Central sands (the upper and lower merge in part of the field), eleven from the Mathews, nineteen from the Cruse, and one from the Good Pine. Commonly only one sand is oil-bearing in any one well, the others containing gas or salt water, depending on structural position.

Seven rigs are now active. The average depth is 2,250 feet. Drilling is rapid, requiring only 4–5 days with light rigs, but the total required time averages nearly 2 weeks per well because of the difficulty of making a completion in the soft bentonitic sands and shales. Ordinarily a selected section of 40–150 feet in the Olla zone is cored and then an electrical survey is made before setting pipe on bottom.

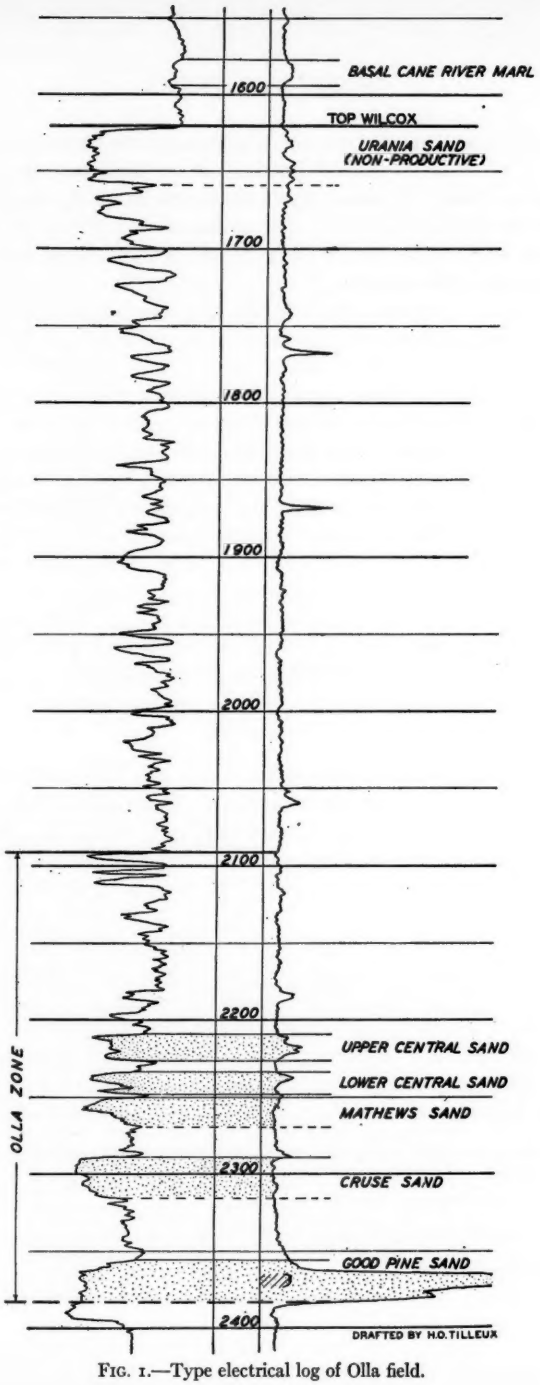

FIG. 1.—Type electrical log of Olla field.

One or more cement squeeze jobs through perforated casing are usually performed to seal off gas and water before perforating for production. These squeezing operations are commonly unsuccessful because the beds are very soft, but no better completion method has been evolved to date. Water produced in volumes of less than 5 per cent is regarded as connate.

The wells generally come in flowing 50–300 barrels per day through ¼-inch choke but some soon require artificial lifting. The gas-oil ratio is about 250 to 1.

Development has been under a program of one well to 40 acres. The present proved area is 5½ miles long from north to south and ¾–2 miles wide east and west with the limits only partly defined.

Currently the field has an allowable of 100 barrels per well per day. The crude is of a desirable type and averages 31.5° gravity for all sands except the Good Pine which averages about 27°.

GOLD, SILVER, AND OTHER ELEMENTS IN SALT-DOME CAP ROCKS[1]

MARCUS A. HANNA[2] AND ALBERT G. WOLF[3]
Houston, Texas

It has been known for several years that cap rocks of Gulf Coastal salt domes contain appreciable amounts, irregularly distributed, of metallic sulphides, including those of iron, lead, zinc, and manganese.[4] Most of these sulphides are found in the calcitic rock and gypsum portions of the cap-rock series; little in the basal anhydrite immediately above the salt.

Nowhere in literature have the writers been able to find any reference to the precious metals gold and silver in cap rocks of Gulf Coastal salt domes. As it is a reasonable assumption that if these metals occur at all they will be in the sulphides, six core samples of cap rocks, from five salt domes in Texas, containing considerable quantities of metallic sulphides were selected and assayed. Fire assays were run for gold and silver by a commercial assayer and lead, zinc, and

[1] Manuscript received, February 25, 1941. Published with permission of the Gulf Oil Corporation and the Texas Gulf Sulphur Company.

[2] Chief paleontologist, Gulf Oil Corporation.

[3] Mining engineer, Texas Gulf Sulphur Company.

[4] Marcus A. Hanna and Albert G. Wolf, "Texas and Louisiana Salt-Dome Cap-Rock Minerals," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 2 (February, 1934), pp. 212–25.

manganese by wet methods. No assays were run for iron which occurs in the form of pyrite.

Table I lists the results of the assays made. Sample No. 1 from Hockley, Harris County, consists mainly of pyrite, some galena, and a little calcite. Sample No. 2, also from Hockley but higher on the dome, is rich in galena, mostly fine-grained, but with cubic crystals of galena and some pentagonal dodecahedrons of pyrite visible under a 10× hand lens. Sample No. 3, from Orchard, Fort Bend County, consists mainly of calcitic rock with considerable insoluble matter, some galena, and a very little pyrite. The galena, for the most part, is fine-grained, but some cubic crystals truncated by octahedrons are visible under a hand lens. The sample for assay was taken from part of the core higher in galena than the average. Sample No. 4, from Boling, Wharton County, is a complex mixture of pyrite, sphalerite, hauerite, native sulphur, calcite, and barite, with some macroscopic crystals of celestite. Sample No. 5, from Clemens, Brazoria County, appears to consist chiefly of gypsum with considerable hauerite and a little native sulphur. The sample assayed contained more hauerite than the average of the entire core from which it was taken. Sample No. 6 from Gulf, Matagorda County, consists of pyrite and calcite, apparently.

TABLE I

Sample No.	*Au*	*Ag*	*Percentage*		
			Pb	*Zn*	*Mn*
1	Tr.	Tr.	8.10	*	*
2	Tr.	Tr.	27.90	*	*
3	Tr.	Tr.	23.70	*	*
4	Tr.	Tr.	*	5.6	5.2
5	Tr.	Tr.	*	*	7.6
6	Tr.	Tr.	*	*	*

* No determinations made.

Knowing that commercial assayers make a practice of reporting traces of gold and silver in any likely-looking sample even where no buttons are obtained on cupellation, the writers made inquiry and the fact was established that no buttons were found. This, of course, was to be expected from the nature of the deposits. The question, however, whether traces of gold and silver actually occur, was not yet answered. Through the courtesy of the Humble Oil and Refining Company the spectroscope was resorted to, with the results shown in Table II.

These spectrographic analyses indicate four elements not hitherto found in cap rocks of salt domes, so far as the writers have been able to ascertain, namely, silver, cadmium, magnesium, and nickel.

TABLE II

No.	*High*	*Medium*	*Low*	*Trace*
1. Hockley	Ca	Zn Pb Fe	Mn Sr Ba Cu	Mg Si As Cd
2. Hockley	Pb	Zn Ca Ba	Sr Mn	Fe Si Al Cd
3. Orchard	Pb Ca	Sr Zn	Ba Mn Fe Mg	Si Cu Al Cd
4. Boling	Ca Sr Zn	Ba Mn	Ni Pb	Al Ag Cd Cu Fe
5. Clemens	Ca	Sr Mn	Fe	Ba Ag Al Cu Pb Mg Ni Si Zn
6.	Ca	Fe Sr Mn	Pb Ba	Mg Cu Al Si Zn

Acknowledgments.—The writers are indebted to F. W. Rolshausen and A. A. Arthur, of the Humble Oil and Refining Company, for spectrographic analyses and to J. W. Schwab of the Texas Gulf Sulphur Company, for chemical analyses.

FORMATION SAMPLES FROM GUN PERFORATORS[1]

J. T. RICHARDS[2]
Oklahoma City, Oklahoma

During the past few years, gun perforators have been used in petroleum development work for two general purposes: first, to explore possible producing formations which were cased off during the drilling of old wells; and, second, for perforating casing opposite recently drilled, producing formations to produce more efficiently oil or gas from the formations or to eliminate mechanical difficulties. Because

[1] Manuscript received, March 3, 1941. Published with permission of the Gulf Oil Corporation and the Lane-Wells Company.

[2] Gulf Oil Corporation.

the greatest effectiveness of the method depends on making perforations opposite those formations which promise production, obtaining samples from the spent shells seemed to offer a means of determining what perforations had been effective and what perforations had not.

Inquiries revealed the fact that the combustion chambers of many of the spent shells contained rock material. Instances were also reported where the bullet projected from the shell had returned to the shell after firing. Further inquiry failed to reveal a single instance where the rock material from a series of shells had been systematically collected and microscopically examined.

Recently, the writer collected and examined the material from 293 spent shells. The material represented 175 feet of strata. The material came from three wells and included limestone, shale, sandstone, cement, and mud. After establishing the fact that rock material in quantities sufficient for microscopic examination does collect in the combustion chambers of spent shells, the question arose whether this material represented the formation opposite the shell at the time of firing. Examination of the samples from the second well answered this question affirmatively. The section perforated in this well ranged from the upper part of the Sylvan shale upward to the Henryhouse member of the Hunton group. The section included an unnamed basal limestone, the Oölitic member, the Glauconitic member, and the Pink Crinoidal member, of the Chimney Hill formation, and the Henryhouse member of the Hunton group. In this group of 91 perforations at 6-inch intervals, the contacts between the several members could be limited to the interval between perforations. Several hundred feet of rotary mud were in the hole, inside and outside the casing, when these perforations were made. The samples obtained from the shells were apparently little contaminated with this mud. If samples collected under these conditions would permit differentiation of several members of relatively similar limestones from one another and of separating them from shale, the distinguishing materials on which the differentiations were made must have come from the formations represented and not from cuttings contained in the mud. The mud in the hole did contribute a small amount of material to the sample but it was easily recognized. In all cases, material derived from the mud was much less than in ordinary rotary samples of good quality.

The following hypothesis is presented as a probable explanation of the accumulation of uncontaminated rock samples in the shells.

First, on penetrating the formation, the bullet displaces by compression, consolidation and brecciation the material occupying the space in its path.

1. This loosened material exists in the form of rock dust and rock fragments.

2. Due to the velocity of the bullet and the vacuum immediately behind a traveling projectile, some of the loosened rock material is drawn into the space opened by the bullet. Possibly gravity pulls some fragments into the space.

4. The loosened rock material is suspended briefly in the gases propelling the bullet.

5. The propelling gases contract immediately after full expansion, generating a suction from the formation to the shell.

6. Since this suction is strong enough to carry bullets from the formation back into the shell, it is also strong enough to carry loosened, shattered rock fragments into the shell.

The exclusion of mud from the shell while rock fragments are traveling from the bullet tunnel and collecting in the powder chamber is a matter of prime importance. An understanding of this is dependent on a knowledge of the operation of the gun and the construction of the shells. Figure 1 is an exterior view of a 10-shot Lane-Wells Gun Perforator. The figure shows five shells arranged spirally on the front of the gun. The other five shells are similarly arranged on the back of the gun. The diameter of the guns varies to meet the requirements of different sizes of casing. The diameter of the gun is ordinarily not more than 1½ inches less than the inside diameter of the casing in which it is used. The length of the gun depends on the number of shell chambers included. In the model illustrated, each shell is fired separately by electrical control. The gun is lowered into a well by a special cable which also carries the necessary electrical circuits. The shells are removable from their chambers in the gun. Figure 2 is a picture of a Lane-Wells shell which has a section cut away to show the interior structure of the shell. The powder chamber at the rear (left) of the shell is considerably larger in diameter than the barrel of the shell, which here holds the bullet (white metallic body with black conical point) in firing position. The greatest volume of sample is ordinarily found in the powder chamber.

Powder packed in the powder chamber supplies energy for propelling the bullet through the casing and into the formation. The burning of this powder generates highly heated gases which, due to their expansion, project the bullet into the formation *and follow it to its point of rest.* Most of the energy of the powder is utilized in propelling the bullet, but as soon as the bullet leaves the muzzle of the shell, the gases begin to expand between the shell muzzle and the inside wall of the casing, forming a "gas pocket" in this space. As soon as the casing

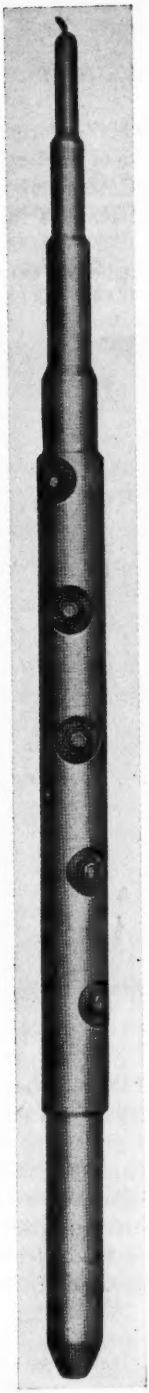

FIG. 1

is pierced, a second "gas pocket" is formed back of the casing and between the casing and the face of the formation. Meanwhile, the inner "pocket" has been growing. Gases follow the bullet into the formation, to its point of rest. Meanwhile, both the inner and outer "pockets" have been growing.

The time element involved is so extremely short that, when the

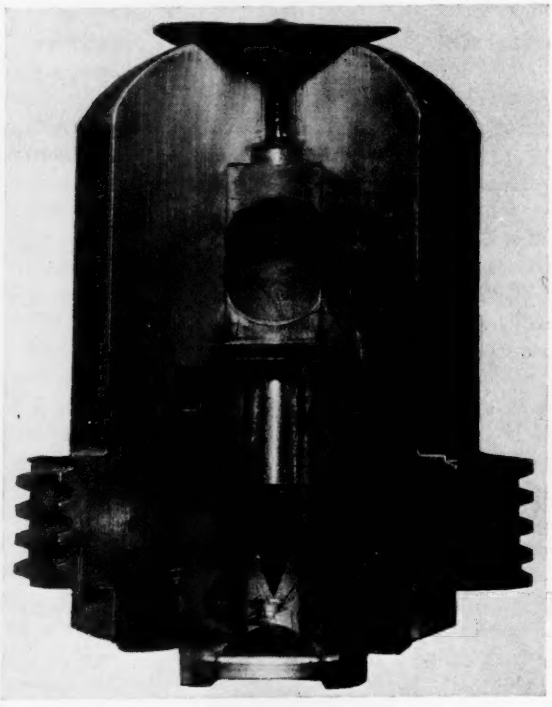

FIG. 2

bullet comes to rest, most of the rock fragments torn from the formation are still floating in the gases. When the bullet has reached its maximum penetration, the gases also have almost or completely reached their maximum expansion. Contraction of the gases occurs and provides the suction which carries the rock fragments back into the shell. The direction and timing of this suction exactly reverse the expanding force. The gases in the bullet tunnel are farthest from the source of heat (the shell), are the last to expand and have the greatest

relative surface for heat losses. Conceivably, these gases may be the smallest in volume also. Accordingly, these distant gases contract first and very rapidly. The gases in the "outer pocket," between the casing and the formation, contract next because they are the next farthest removed from the source of heat, were next to the last to expand and have the next largest radiating surface. In like manner, the "inside pocket" then contracts and finally the gases in the shell itself cool and contract more slowly because of their protected position within the shell. Therefore, at least a part of the rock fragments which are floating in the gases in the bullet tunnel are carried by the contracting gases from the bullet tunnel to the shell without contacting any mud in their travel and are deposited in the shell in an uncontaminated state. If sufficient rock fragments are not brought to the shell to fill the powder chamber and barrel, the remaining space is filled with whatever material is at hand, mud, water, oil, or gas. Mud will introduce some contamination if it contains foreign rock material. The volume of material collected depends partly on the amount of rock material available which, in turn, is dependent on the depth of formation penetration by the bullet, kind of rock penetrated, fluid content of the rock, and probably many other unknown factors. The more brittle rocks seem to furnish the larger samples.

The volume of sample recovered from a shell is chiefly a function of the size of the shell. The relative sizes of the gun, casing, and hole also affect the volume collected. The size of the powder charge also considerably influences the sample volume but neither the qualitative nor the quantitative measure of this factor is yet known. In general, the amount of sample available from a shell is about one-tenth of the individual, enveloped sample usually furnished a geologist for examination from ordinary drilling operations. For example, if a 10-foot zone is perforated at one-foot intervals, the total volume of the ten samples taken from the shells is about equal to the ordinary "cut" of samples received from 10 feet of drilling. Perforating samples give one-foot control on formation changes in such instances.

The technique of collecting, washing, drying, examining, and filing perforating gun samples is a matter which will be developed more fully with greater experience. The procedure for the field treatment of the samples herein discussed was as follows. Before it was placed in the gun, each shell was numbered with wet chalk on the inside, cylindrical surface to correspond with the firing order of the gun. After firing, the shells were taken from the gun in the order of firing and placed in trays numbered in the order of shooting. Thus, the number on the shell corresponded with the number on the tray. All shells were filled

with water as soon as possible to prevent caking of any mud present. A long, thin paddle, just narrow enough to pass through the barrel, was inserted and rotated rapidly to loosen all material in the powder chamber and barrel. The shell was then inverted over a funnel leading to an 8-ounce prescription bottle and as much as possible of the contents of the shell allowed to flow into the funnel. With the shell still inverted, the remaining material was washed from the shell by inserting the neck of a 3-ounce ulcer syringe into the chamber, through the barrel, and jetting water into the chamber and catching the return in the funnel. Rotating the shell while washing facilitated removal of rock fragments. Two syringes were employed, one filling while the other was being emptied. The bottles used in this operation, called wash bottles, were numbered consecutively with indelible pencil on surgeon's tape. Twenty wash bottles were used. After removing all material from the funnel into the wash bottle, the bottle was closed with the thumb and shaken violently to break any clots of mud. Washing was effected by elutriation. Water for this purpose was siphoned from an elevated bucket through rubber tubing equipped with glass tubing tips melted down to apertures sufficiently small to prevent wastage of the finer rock material but large enough to agitate the sample thoroughly. To hasten washing, two or more tubes may be used simultaneously, one for each bottle of a battery.

When the overflow water became clear, elutriation was stopped and the bottle shaken again. If the water remained clear, the sample was considered washed sufficiently. If the water became murky, washing was resumed. Clean water from the wash bottle was drained back into the elevated bucket to save water carrying. A small amount of water remained, which was used to wash the bulk of the sample towards the neck of the bottle. With a gentle stream of water from a syringe, the sample was washed from the wash bottle onto a filter paper which had been numbered on both sides of the paper to correspond with the number of the perforation. A soft black pencil was used for marking the filter papers. If drying facilities were available in the field, the samples were dried on the filter paper, folded carefully into the paper, and the paper and sample placed in an ordinary sample envelope which was also numbered to correspond with the perforation number. If no drying facilities were available, the wet samples were carefully folded into the wet filter papers and the whole series of wet samples carefully packed into a glass jar. These were later dried in the laboratory and enveloped. The samples were retained in the filter papers after drying because the volumes were small and less wastage resulted.

Wet samples were usually examined microscopically in the field immediately after washing and checked later, when dry. When the dried samples were enveloped, the perforating data and the samples were brought together. The operator of the perforating gun furnished the depth corresponding with the number of each shell. The depth was placed on each sample envelope as it was examined and logged. These were then properly marked and filed with the other samples from the well.

No claim of perfection is made for the procedure here outlined. Different field conditions and different formations may exact modifications which must be left to the resourcefulness and ingenuity of the individual geologist. Undoubtedly, satisfactory methods can be devised for handling and examining samples of this kind on location, where their value is greatest.

Samples obtained from gun perforations may have wide and varied uses, provided sufficient quantities can be obtained and the origin of the material can be definitely established. No attempt is made here to discuss any phase of the problems of application because the data at hand are so meager as to preclude such discussion. It is the purpose of this article merely to present data obtained from one area in the Mid-Continent field and solicit similar data from any other area where any type of a gun perforator is used to project bullets into rocks. It seems possible that samples obtained in this manner may add materially to knowledge of underground strata and conditions.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 4 (APRIL, 1941), PP. 760-771

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and are available, for loan, to members and associates.

GEOPHYSICS, 1940, BY THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

REVIEW BY JOHN L. FERGUSON[1]
Tulsa, Oklahoma

"Geophysics, 1940." *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 138 (New York, 1940). 489 pp., illus. Cloth. Price, $5.00 net.

This is a compilation of certain geophysical papers presented at meetings of the Institute from February, 1935, to February, 1940, inclusive. They are published under the direction of Sherwin F. Kelly, who has contributed the introduction and one paper, which together give an excellent summary of the history and application of geophysical instruments.

There are 38 papers collected under the headings of Geophysical Education, General, Magnetic Methods, Gravitational Methods, Seismic Methods, Electrical Methods, Electromagnetic Methods, and Radioactive Methods. All but one of these papers have been published separately by the Institute as *Contributions* or *Technical Papers*.

The papers on Geophysical Education were presented at a symposium in February, 1938, which sought to determine the proper scholastic preparation for a career in geophysics. Five papers were presented with discussions and a committee report.

The General papers include a hitherto-unpublished dissertation on "Research Needed in Economic Geology," by T. S. Lovering, and a discussion of the geological, magnetic, and gravitational features of Sao Pedro area, Brazil, by Mark C. Malamphy. This latter paper concludes that the geologic structures are laccolithic in origin, and "there is little probability of discovering petroleum in commercial quantities in this region."

Under Magnetic Methods eight papers are listed. These are largely expositions of new methods of handling data or of surveys of mining prospects. Most of the papers were given in 1935–37.

Gravitational Methods includes four titles, three of which are concerned with descriptions of various types of gravimeters, which have largely replaced torsion balances for gravitational exploration during the last 5 years. Heiland's paper, "The Relation of Gravimeters to Seismometers, Astatization, and Calibration," is an earlier version of his discussion of gravimeters in his new book on geophysical prospecting.

The section on Seismic Methods is introduced by a Symposium on Seismograph Prospecting for Oil given at the September meeting, 1938, by five members of the Superior Oil Company of California. This is probably the first and only clear exposition of seismic prospecting that has ever been written, and the result has been achieved without the interpolation of a single mathematical formula or the use of a single diagram. The treatment begins with an intro-

[1] Amerada Petroleum Corporation. Manuscript received, February 13, 1941.

duction by Walter A. English giving seismograph prospecting its setting in petroleum exploration. Willard H. Tracy then sets forth in understandable terms the theory of seismic-reflection prospecting with emphasis on the types of waves involved. The instruments used in reflection prospecting are clearly explained, without the use of diagrams, by Arthur Nomann. Frank Ittner takes up the highly variable factors of spread, hole depth, and record character in a consideration of field operations. The final section on determining geologic structure from seismograph records is handled by P. C. Kelly. This most difficult phase in the study of reflection shooting is covered well up to the point of getting the computed data properly represented, and then Kelly lets his subject slide. However, he winds up with a neat evaluation of the overpublicized controversy regarding the merits of geologists versus geophysicists as interpreters of the final map.

Additional papers pertaining to seismic methods include three which concern themselves with technical details of calculation or observation by exploratory seismograph parties. The remaining four papers have to do with the use of seismic equipment in recording near-surface vibrations.

Under Electrical and Electromagnetic Methods there are five papers concerned with new approaches to the solution of technical problems. One broad regional study by R. H. Card discusses the "Correlation of Earth Resistivity with Geologic Structure and Age." His conclusion that there is a general increase in resistivity with increase in age of beds is not supported by his data or by his areal maps. Geologists will find his use of the term "structure" as virtually synonymous with "stratigraphic section" somewhat confusing.

Only one paper is included under Radioactive Methods, being a very preliminary study of the possibilities of stratigraphic correlation by radioactive qualities of the various formations by H. Landsberg and M. R. Klepper.

For the geologist or mining engineer interested in the application of geophysics to the search for petroleum or minerals, there are very few papers which will shed light on his problems. To a former member of the Institute it seems that the volume includes too many papers pertaining solely to technical and operative problems of geophysics which should rightfully appear in a more suitable publication.

SMALL FORAMINIFERA FROM THE LATE TERTIARY OF THE NEDERLANDS EAST INDIES, BY L. W. LEROY

REVIEW BY M. C. ISRAELSKY
Houston, Texas

Small Foraminifera from the Late Tertiary of the Nederlands East Indies, by L. W. LeRoy. *Colorado School of Mines Quarterly*, Vol. 36, No. 1 (January, 1941).

It would be impertinent for one unfamiliar with the East Indies to attempt a critical review, so none is essayed.

After a title page and foreword comes a welcome map of the Dutch East Indies, obviating search for an atlas or borrowing a youngster's geography.

A preface follows which shows the commonly used alphabetical stratigraphic breakdown in relation to the standard Tertiary scale. Oostingh's stage names for the Neogene of the region are given, and these divisions, according to the author, are substantiated by the microfossils.

Due to the apparent isolation of the area, epochal or stage terms of European origin should be used with reservations, at least until much more work is done. A table on page 6 suggests the relationships of the European epochs and stages to the alphabetical divisions used in the East Indies, together with the provincial ranges of several larger Foraminifera.

PART 1. SMALL FORAMINIFERA FROM THE LATE TERTIARY OF THE SANGKOELIRANG BAY AREA, EAST BORNEO, NEDERLANDS EAST INDIES

Systematically recorded are "150 species representing 78 genera" and "seven species and one variety have been described as new" by the author, two by Dorn. Some notes are given on the stratigraphy and excellent faunal comparisons are given with both fossil and recent assemblages.

Described as new are the following.

Spiroplectammina marginoacuta LeRoy
Textularia diverga Dorn (ms)
Clavulinoides tricarinatus LeRoy
Pseudoglandulina acuta LeRoy
Bulimina microlongistriata LeRoy
Bifarina crenulata LeRoy
Eponides punctatus LeRoy
Rotalia equatoriana LeRoy
Orbulina universa d'Orbigny var. *bisphaerica* LeRoy
Cibicides concavus Dorn (ms.)

An index map (p. 12) and four pictures of assemblages (pp. 15, 16) are included in this section, together with three plates of Foraminifera and a species index.

PART 2. SMALL FORAMINIFERA FROM THE LATE TERTIARY OF SIBEROET ISLAND, OFF THE WEST COAST OF SUMATRA, NEDERLANDS EAST INDIES

The treatment is similar to Part 1. An index map appears on p. 64, and four pictures of assemblages are given (pp. 67, 68).

"One hundred and twenty-eight species are considered. Six species and four varieties of Foraminifera are described as new."

These are the following.

Spiroplectammina expansa LeRoy
Quinqueloculina reticulata (d'Orbigny) var. *elongata* LeRoy
Robulus evolutus LeRoy
Robulus multi-marginatus LeRoy
Robulus sutura-rectus LeRoy
Nodosaria insecta Schwager var. *spinifera* LeRoy
Lagenanodosaria scalaris (Batsch) var. *hispida* LeRoy
Lagena costaspiralata LeRoy
Eponides mentaweiensis LeRoy
Tinoporus baculatus (Montfort) var. *sphaericus* LeRoy

Seven plates accompany this part.

PART 3. SOME SMALL FORAMINIFERA FROM THE TYPE LOCALITY OF THE BANTAMIEN SUBSTAGE, BODJONG BEDS, BANTAM RESIDENCY, WEST JAVA, NEDERLANDS EAST INDIES

The treatment follows that of the previous two parts, there being an index map (p. 108) and a single assemblage figure on p. 111. In addition a table of the sedimentary and faunal sequence of West Java is given.

"Forty-seven species" are considered.

New species are the following.

Discorbis bodjongensis LeRoy
Rotalia marginospinosa LeRoy
Globigerinoides sacculiferus (Brady) var. *immatura* LeRoy
Cibicides soendaensis LeRoy
Cibicides bantamensis LeRoy

Three plates accompany this part.

A list of 46 references and a complete index of Foraminifera for the three papers terminate the number.

The sole complaint is the small size of the figures in Part 1.

The make-up is excellent as are the half-tone plates.

The author has done a remarkable work in a short time. His opportunity to illustrate his faunules completely is to be envied.

THE DIVISIONS OF THE TERTIARY OF NEW ZEALAND, BY H. J. FINLAY AND J. MARWICK

REVIEW BY HUBERT G. SCHENCK[1]
Stanford University, California

"The Divisions of the Tertiary of New Zealand," by H. J. Finlay and J. Marwick. *Proc. Sixth Pacific Science Congress, 1939*, Vol. 2 (1940), pp. 505–21. University of California Press, Berkeley, California.

This is the fifth of a series of reviews of important papers published in the *Proceedings of the Sixth Pacific Science Congress*, the four previous reviews appearing in this *Bulletin*, Vol. 24, pp. 2049–52.

The notable contribution by Finlay and Marwick is the first classification of the Tertiary of New Zealand which presents clearly the method followed and the criteria employed in setting up their stages of the 13,614+ feet of Tertiary sediments. The New Zealand stages are tabulated as follows.

TABLE I

Suggested European Equivalents		*New Zealand Stage*		*Thickness in Feet*
Pliocene	Upper*	Castlecliffian		1,200+
	Middle	Nukumaruan		500
	Lower	Waitotaran		1,500
		Opoitian		4,000
Miocene	Upper	Urenuian	(Taranakian)	1,500
		Tongapoturuan		1,400
	Middle	Awamoan		50
	Lower	Hutchinsonian		20
Oligocene	Upper	Waitakian		150
		Duntroonian		4
	Middle	Whaingaroan	(Ototaran)	100
	Lower	Kaiatan		2,000–3,000
Eocene	Upper	Tahuian	(Waimatean)	50
	Middle	Bortonian		50
	Lower	.....		

* The terms "Upper," "Middle," and "Lower" are relative only; they are not meant to apply with exactitude.

[1] Manuscript received, February 21, 1941.

Reasons for the suggested European correlations are given on pages 506–11. Here is some of the more important evidence.

Bortonian (Eocene).—The Eocene age of this stage is proved by the presence of *Discocyclina*, *Asterocyclina*, and questionably *Assilina*. Several smaller foraminifers are closely related to American species, for example: *Marginulinopsis asperuliformis* (Nuttall) of the Mexican Aragon is extremely close to the lowest Bortonian *M. waiparaensis* Finlay. Several of the mollusks suggest that the Bortonian is medial Eocene in age.

Duntroonian and Waitakian (upper Oligocene).—In this part of the Tertiary are numerous fossil Cetacea, some of which are related to European upper Oligocene species and some to lower Miocene forms. The data suggest that these two stages may be about Aquitanian in age—the much-debated European stage placed by some specialists in the Miocene, by others in the Oligocene.

Hutchinsonian (lower Miocene).—The foraminiferal genus *Miogypsina* appears for the first time in and is restricted to the Hutchinsonian stage. Several species of *Lepidocyclina*—all belonging to the subgenus *Nephrolepidina*—are present in this stage, which is correlated with the Australian Janjukian stage.[2] The distinctive gastropod *Typhis maccoyi* is known only from the Australian Janjukian-Balcombian and the Hutchinsonian-Awamoan of New Zealand. Other evidence is adduced to prove the early Miocene age of the Hutchinsonian stage.

Opoitian and Waitotaran (lower Pliocene).—The foraminiferal species *Uvigerina pigmea* d'Orbigny is restricted to this part of the section; this suggests an age relationship with the Italian Plaisancian stage. *Bulimina echinata*, which was described originally from the Italian Pliocene, is also present in the Australian Kalimnan (lower Pliocene) and in beds in New Zealand assigned to the lower and middle Pliocene. In Australia, *Rectobolivina striatula* (Cushman) ranges from Kalimnan to Recent; in New Zealand the range is from latest Miocene to Recent. In Opoitian age appears for the first time a modern-like globigerinid assemblage with *Globorotalia truncatulinoides*, *Globigerinoides ruba*, and *Globigerinoidea sacculifera*.

Definition of stages.—The authors follow a uniform system in defining the stages: (1) type locality, (2) sediments, (3) fauna, (4) correlatives, (5) restricted forms, (6) first appearance of, and (7) last appearance of certain fossils. How this scheme is applied may be seen from the following quotation (page 516) defining the Urenuian stage.

URENUIAN

Type locality.—Coast, Urenui, North Raranaki.

Sediments.—Argillaceous sandstones 1,500 ft. thick, on coast angularly unconformable to Tongaporutuan.

Fauna.—Mollusks and forams rather common, often poor, not much specific change from Tongaporutuan.

Correlatives (by mollusks and forams).—Waiapu Subdivision, East Cape district (sandstones generally unconformable to Lower Raranakian).

[2] J. Makiyama, "The Neogenic Stratigraphy of the Japan Islands," *Proc. Sixth Pacific Science Congress*, Vol. 2 (1940), p. 642, reports *Miogypsina* and *Lepidocyclina nipponica*—a nephrolepidina—from the Ooigawan stage, which is perhaps lower Miocene, though Makiyama considers the subjacent Asagaian stage is about the equivalent of the Aquitanian, hence either upper Oligocene or lower Miocene.—Reviewer's note.

Restricted forms.—(M)[3] *Neilo waitaraensis* Marw., *Struthiolaria praenurtia* Marw., *Pelicaria nana* (Marw.), *Heligmope pehuensis* (Marw.), *Falsicolus tangituensis* (Marw.), *Alcithoe solida* Marw., *Lithoconus* (large spp.).

(F)[3] Probably undescribed species of *Bolivinita*, *Loxostomum*, and *Rectobolivina*.

First appearance of.—(M) *Heligmope* Tate, *Pelicaria* Gray, *Ellicea* Fin., *Waitara* Marw.; (F) *Rectobolivina striatula* (Cush.).

Last appearance of.—(M) *Nucula* Lamk. (large spp.), *Lentipecten* Marw., *Notomyrtea* Ired., *Kuia* Marw., *Fossacalista* Marw., *Magnatica* Fin., *Euspinacassis* Fin., *Falsicolus* Fin., *Baryspira* Fisher (with heavy callus), *Bathytoma* H. and B.

(F) *Sigmoilina celata* (Costa), *Robulus dicampylus* (Franz.), *Cassidulina murrhyna* (Schw.), *Pseudononion stachei* (Cush.). Some of the Tongaporutu "last appearances" will probably extend to Urenuian when the faunas are better known.

Restricted forms.—The stages were apparently set up chiefly on a paleontological basis. Hence, the fossils restricted to the several units assume considerable importance. To list all of these genera and species is uncalled for here, but attention may be directed to the fact that the definition of each stage is in terms of a combination of long- and short-ranging and restricted genera and species of both microfossils and megafossils. This technique agrees with the analysis of kinds of occurrences itemized by Adams[4] as necessary in establishing any time-stratigraphic unit. This is the type of paleontological analysis employed by Kleinpell in establishing stages of the California Tertiary.[5]

First and last appearances.—Table II lists the total ranges of only a few of the New Zealand fossils—the table is merely a sample of what one may learn from the paper. The end points of the range lines are the first and last records as given by the authors. The connecting lines have been drawn by the reviewer. The *en échelon* nature of these ranges is familiar to economic paleontologists and to those who have attempted to delimit time-stratigraphic units. The reader will understand, of course, that the ranges given in Table II are for New Zealand only, and that total ranges alone will not define time-stratigraphic units. Nevertheless, even relatively long-ranging fossils may aid in defining them. For example, the mutual occurrence in the same stratum of *Flabellamina*, *Frankeina*, *Chama*, *Hipponyx*, *Olivella*, and *Scaphander* would aid in allocating the stratum to the Hutchinsonian stage. *Cyclocardia*, *Gigantostrea*, and *Lima* would not be sufficient to place any bed in any one stage, but if these mollusks were associated with *Niso*, one would search for other evidence to verify the suspicion that the stage is the Duntroonian.

Bibliography.—The final section of the paper is a list of references—seventy-three titles of papers dealing with stratigraphy, paleontology, and correlations. Micropaleontologists will be interested particularly in Finlay's papers on New Zealand foraminifers published in the *Transactions of the Royal Society of New Zealand*, Volumes 68 and 69.

Remarks.—The reviewer is of the opinion that the authors should have selected as type localities of the several stages those places where the subjacent and superjacent stages are present in the same section and in similar facies. Of all the stages, only the Tahuian and Duntroonian rest conformably upon rocks of the subjacent stages at their type localities, and even these apparently are not overlain by the next younger stages in the same section.

[3] "M" is for *Mollusca;* "F," *Foraminifera.*

[4] B. C. Adams, "Foraminifera in Zonal Paleontology," *Proc. Sixth Pacific Sci. Congress*, Vol. 2 (1940), p. 668.

[5] R. M. Kleinpell, *Miocene Stratigraphy of California* (Amer. Assoc. Petrol. Geol., 1938). 450 pp.

TABLE II

TOTAL RANGES OF SOME TERTIARY FOSSILS IN NEW ZEALAND

Fossil \ Stage	Eocene		Oligocene				Miocene				Pliocene			
	Bortonian	Tahuian	Kaiatan	Whaingaroan	Duntroonian	Waitakian	Hutchinsonian	Awamoan	Tongapoturuan	Urenuian	Opoitian	Waitotaran	Nukumaruan	Castlecliffian
Bonellitia	—	—	—	—	—	—	—	—	—	—	—			
Galeodea	—	—	—	—	—	—	—	—						
Niso	—	—	—	—	—									
Conospirus		—	—	—	—	—	—	—						
Nemocardium (large forms)			—	—	—	—	—	—						
Flabellamina				—	—	—	—							
Frankeina				—	—	—	—							
Polymorphina				—	—	—								
Cyclocardia					—	—	—	—						
Gigantostrea					—	—	—	—	—	—	—	—	—	
Lima					—	—	—	—	—	—	—	—	—	
Typhis						—	—	—	—	—	—			
Chama							—	—	—	—	—	—		
Hipponyx							—	—	—	—	—			
Olivella							—	—	—	—	—	—		
Scaphander							—	—	—	—	—	—		
Migros								—	—					
Uvigerina mioschwageri								—	—					
Plectofrondicularia pohana									—	—	—			
Plectofrondicularia pellucida											—	—	—	—

As a final word, the reviewer wishes to express at this time his appreciation of this fine contribution by Finlay and Marwick and he awaits with more than usual interest their reports on the testing of the stages by even more detailed studies.

PALEOZOIC FORMATIONS OF THE JAPANESE ISLANDS, BY HISAKATSU YABE

REVIEW BY HUBERT G. SCHENCK[1]
Stanford University, California

"Paleozoic Formations of the Japanese Islands," by Hisakatsu Yabe. *Proc. Sixth Pacific Science Congress, 1939*, Vol. 1 (1940), pp. 377–92. University of California Press, Berkeley, California.

In 1936, Y. Onuki discovered richly fossiliferous Gotlandian (Silurian) deposits in the Kitakami mountain land near Sakari, Kesen-gun, Iwate-ken.[2] Further investigation disclosed the presence of Devonian, Carboniferous, Permian, and Lower Triassic formations in that region; hence, the Silurian-Permian succession there is now taken as the standard section of the Paleozoic sediments of the Japanese archipelago. For the purposes of this review, the Upper Paleozoic section receives more emphasis than the Silurian and Devonian.

The following is a summary of the lower part of the section in the Kitakami region.

Tyoanzi series (lowest Carboniferous)
Tuff and fossiliferous limestone; thickness, 600 meters
Omori series (Neo-Devonian)
Tuff, locally calcareous; some fossils; thickness, 500 meters
Nakazato series (Meso-Devonian)
Tuff, conglomerate; some radiolarian deposits; *Phacops* bed near top; thickness, 600–700 meters
Ono series (Eo-Devonian)
Green slate, some limestone; abundant fossils; thickness, 70–100 meters
Takainari series (probably Neo-Gotlandian)
Green adinole with reddish purple radiolarian slate at base; thickness 100–150 feet
Kawauti series (Meso-Gotlandian)
Limestone and slate; richly fossiliferous; thickness, 150–200 meters

The following is a summary of the Upper Paleozoic section of the Kitakami area.

Neo-Permian
Toyoma series
Chiefly black slate and shale; thickness, 1,500 meters. Conformable with subjacent series. Fossiliferous in lower part: *Nuculites kimurai, Palaeoneilo ogachiensis, Bellerophon, Cycloceras* cf. *cyclophorum*, and *Thamnopora*

Eo- and Meso-Permian
Maiya series
Black slate, limestone lenses locally; thickness, 500–2,000 meters. Usuginu conglomerate lenticular in this and superjacent series. Sakamotozawa conglomerate at base. Unconformable with subjacent series
Upper division fossils: *Condonofusiella* aff. *paradoxica, Parafusulina, Verbeekina, Yabeina, Mizzia velebitana, Waagenophyllum indicum, et cetera.* This division is correlated with Artinskian stage
Lower division fossils: *Pseudoschwagerina, Quasifusulina, Schwagerina, Staffella, Nipponitella, et cetera.* This division is correlated with Sakmarian stage

[1] Manuscript received, February 21, 1941.

[2] The locality is approximately 39° N. Lat., 142° E. Long. The locality is spelled "Kitami" on the reviewer's atlas and is shown to be northeast of Sendai.

Carboniferous
Onimaru series
Upper division: black shale with some sandstone and limestone with *Chaetetes asiaticus, Fusulinella, et cetera.* Correlated with Moscovian stage
Lower division: coralline limestone with conglomerate at base. Unconformable on older strata. Fossils: *Endothyra, Ozawainella, Dibunophyllum, Diphyphyllum Hexaphyllia, Lithostrotion, et cetera.* Correlated with Visean (Upper Dinantian), that is, approximately Mississippian of American scale

The famous Akasaka limestone has been divided by Ozawa into twelve beds; these are described on page 388. *Parafusulina japonica* in this limestone is reported to be associated with *Pseudodoliolina, Verbeekina, Neoschwagerina, "Doliolina,"* and *Fusulinella.*

Among the noteworthy facts brought out in this paper, attention is directed particularly to these three. (1) The mutual occurrence of *Yabeina* with *Verbeekina, Neoschwagerina,* and *Parafusulina* seems to be confirmed by many records. The reviewer begins to wonder if the "more advanced types" of fusulinid foraminifers may not be to some extent man-made interpretations based on *a priori* assumptions. (2) Another noteworthy statement is that *Ozawainella* occurs in limestone of Visean (Upper Dinantian) age. (3) That *Fusulinella* ranges into the Permian, perhaps as high as Artinskian, appears to be established.

RECENT PUBLICATIONS

CALIFORNIA

*"Eocene Annauxite Clays and Sands in the Coast Range of California," by Victor T. Allen. *Bull. Geol. Soc. America,* Vol. 52, No. 2 (New York, February 1, 1941), pp. 271–94; 2 pls., 3 figs.

*"Some Ideas on the Extension of Torrance-Wilmington Productive Area," by Vernon L. King and Harold M. Preston. *California Oil World,* Vol. 34, No. 4 (Los Angeles, February, 2d issue), pp. 5–9; 3 photographs, 1 subsurface structure map.

CANADA

*"Investigating Front Field Fold, Eastern Flank of Turner Valley Structure," by Alex Higgins. *Canadian Oil and Gas,* Vol. 1, No. 8 (Toronto, February, 1941), pp. 21–23; cross section and map.

CUBA

*"Review of Oil Activities in Cuba during 1940," by R. H. Palmer. *International Oil,* Vol. 2, No. 1 (Houston, January, 1941), pp. 45–48; 7 figs.

ENGLAND

*"Some Variations in Echinocorys in South-Eastern England," by John F. Hayward. *Proc. Geologists' Assoc.,* Vol. 51, Pt. 4 (London, January 24, 1941), pp. 291–310; 5 figs.

*"A Contribution to the Pleistocene History of the Upper Darent Valley," by F. Fossling. *Ibid.,* pp. 311–40; 4 figs., 2 pls.

*"The Purbeck Beds of Swindon," by P. C. Sylvester Bradley. *Ibid.,* pp. 349–72; 3 figs.

*"Ostracoda from the Portland and Purbeck Beds at Swindon," by F. W. Anderson. *Ibid.,* pp. 373–84; 2 pls.

*"Report on Mollusca from the Pebbly Sand below the Roach Bed at Swindon," by W. J. Arkell. *Ibid.*, pp. 385–40; 4 figs.

GENERAL

*"Geophysics, 1940." *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 138 (29 West 39th Street, New York, 1940). 489 pp., illus. 6×9 inches. Cloth. Papers and discussions presented at meetings held at New York, February 18–21, 1935; February 17–21, 1936; February 15–19, 1937; February 14–17, 1938; February 13–16, 1939; February 12–15, 1940. Price, $5.00, net.

*"Geochemical Calculations Concerning the Total Mass of Sediments in the Earth," by Ph. H. Kuenen. *Amer. Jour. Sci.*, Vol. 239, No. 3 (New Haven, Connecticut, March, 1941), pp. 161–90; 2 tables.

Temperature: Its Measurement and Control in Science and Industry. Papers presented at a symposium held in New York City, November, 1939, under the auspices of the American Institute of Physics with the coöperation of the National Bureau of Standards, the National Research Council, and officers and committees of twelve scientific societies. 1,362 pp., many illustrations, tables, bibliographies, a glossary, and author and subject indexes. 6×9 inches. Cloth. Reinhold Publishing Corporation, 330 West Forty-Second Street, New York (1941). Price, $11.00.

*"Rôle of Clay and Other Minerals in Oil-Well Drilling Fluids," by A. George Stern. *U. S. Bur. Mines R. I. 3556* (February, 1941). 88 multigraphed pp., 30 figs., 3 tables.

**Bibliography and Abstracts of Papers on Reservoir Conditions and Mechanics*, by Amer. Assoc. Petrol. Geol. Pacific Section Study Group (November, 1940). Approx. 70 mimeographed sheets perforated into 4 cards each. For sale by H. K. Armstrong, 1002 Edison Building, Los Angeles, California. Price, $0.50 plus $0.25 mailing costs.

*"Measure of Gas Leakage Applied to Oil Search," by Sylvain Pirson. *Oil and Gas Jour.*, Vol. 39, No. 41 (Tulsa, February 20, 1941), pp. 21 and 32.

*"Origin of Line of Color Change in Red Bed Deposition," by G. E. Anderson. *Bull. Geol. Soc. America*, Vol. 52, No. 2 (New York, February 1, 1941), pp. 211–18; 3 figs.

IDAHO, MONTANA, WYOMING

*"Permo-Triassic Boundary in Idaho, Montana, and Wyoming," by Norman D. Newell and Bernhard Kummel. *Amer. Jour. Sci.*, Vol. 239, No. 3 (New Haven, Connecticut, March, 1941), pp. 204–08; 1 pl., 2 figs.

ILLINOIS

*"South Central Illinois," compiled by *Oil and Gas Jour.*, Vol. 39, No. 41 (Tulsa, February 20, 1941), pp. 58–59; map of areal geology and stratigraphic section in colors.

ITALY

*"Il problema delle rocce madri nella ricerca del petrolio in Italia" (Petroliferous Rocks in Italy), by Michele Gortani. *Materie Primie d'Italia e dell' Impero Ressegna Mineraria Mensile*, Vol. 5, No. 12 (Rome, December, 1940), pp. 472–79.

KANSAS

The following bulletins of the Kansas Geological Survey, Lawrence, Kansas, are available in one cloth-bound volume. 6×9 inches.

"Ground-Water Resources of Kansas," by Raymond C. Moore *et al. Kansas Geol. Survey Bull. 27* (Lawrence, June 25, 1940). 112 pp., 28 figs., 34 pls.

"Exploration for Oil and Gas in Western Kansas during 1939," by Walter A. Ver Wiebe. *Ibid., Bull. 28* (July 25, 1940). 106 pp., 34 figs.

"Asphalt Rock in Eastern Kansas," by John M. Jewett. *Ibid., Bull. 29* (June 30, 1940). 23 pp., 2 pls., 3 figs.

Oil and Gas in Linn County, Kansas," by John M. Jewett *et al. Ibid., Bull. 30* (September 30, 1940). 29 pp., 3 pls., 7 figs.

"Oil and Gas in Montgomery County, Kansas," by G. E. Abernathy *et al. Ibid., Bull. 31* (September 15, 1940). 29 pp., 6 figs., 2 pls.

"Coal Resources of Kansas: Post-Cherokee Deposits," by R. E. Whitla. *Ibid., Bull. 32* (September 1, 1940). 64 pp., 5 pls., 28 figs.

"Subsurface Mississippian Rocks of Kansas," by Wallace Lee and George H. Girty. *Ibid., Bull. 33* (September 1, 1940). 112 pp., 4 figs., 2 tables, 10 pls.

LOUISIANA

*"Geology of Avoyelles and Rapides Parishes," by H. N. Fisk. *Louisiana Geol. Survey Bull. 18* (New Orleans, September, 1940). 240 pp., frontispiece, 12 pls., 50 figs.

*"Cretaceous Outcrops in Louisiana," by R. Dana Russell. *Oil*, Vol. 1, No. 2 (New Orleans, March, 1941), pp. 32–33; 3 figs.

*"The Anse La Butte Oil Field," by Cyril K. Moresi. *Ibid.*, pp. 39–42; 4 photographs, 2 tables.

MISSISSIPPI

*"Paynes and Enid Structural Prospects." *Mississippi Geol. Survey Memorandum for Press* (University, February 1, 1941). 2 mim. pp.

*"Mississippi Geology," by William Clifford Morse. *Oil*, Vol. 1, No. 1 (232 Balter Building, New Orleans, Louisiana, February, 1941), pp. 37–40, 42; 14 photographs.

*"The Upper Cretaceous Deposits," by Lloyd William Stephenson and Watson Hiner Monroe. *Mississippi Geol. Survey Bull. 40* (1940). 296 pp., 48 figs., 15 pls.

NEW MEXICO

*"Geology of the Moreno Valley, New Mexico," by Louis L. Ray and J. Fred Smith, Jr. *Bull. Geol. Soc. America*, Vol. 52, No. 2 (New York, February 1, 1941), pp. 177–210; 6 pls., 2 figs.

OKLAHOMA

*"Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma, Pt. 5, Townships 26 and 27 North, Ranges 10 and 11 East," by L. E. Kennedy, W. E. Shamblin, Otto Leatherock, and N. W. Bass. *U. S. Geol. Survey Bull. 900-E* (December, 1940), pp. 173–208; Pl. 5. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.40.

OREGON

*"Jurassic Stratigraphy of Central Oregon," by R. L. Lupher. *Bull. Geol. Soc. America*, Vol. 52, No. 2 (New York, February 1, 1941), pp. 219–70; 4 pls., 3 figs.

ROCKY MOUNTAINS

**Résumé Rocky Mountain Oil and Gas Operations for 1940*, edited by C. E. Shoenfelt. 154 mimeographed pp., illustrated by structure maps. Annual report on region of Colorado, Montana, New Mexico and Wyoming. Approx. 8.25×10.75 inches. Paper cover.

ROUMANIA

*"Manifestations salines dans la zone interne du Flysch" (Saline Evidence in the Interior Zone of the Flysch), by Ion Băncilă. *Comptes Rendus Inst. Sciences Roumania*, Vol. 4, No. 3–4 (Bucureşti, May–August, 1940), pp. 331–34. In French.

TEXAS

*"Hawkins Field, Southeastern Wood County, Texas," compiled by *Oil and Gas Jour.*, Vol. 39, No. 40 (Tulsa, February 13, 1941), pp. 32–34; development map.

*"Hawkins Is New Woodbine Field in East Texas Area," by H. Lee Flood. *Petrol. Eng.*, Vol. 12, No. 5 (Dallas, February, 1941), pp. 25–26; 4 photographs, 1 table.

*"Hawkins Field Is Valuable Addition to Nation's Reserves," by M. T. Halbouty. *World Petrol.*, Vol. 12, No. 2 (Hoboken, New Jersey, February, 1941), pp. 24–26; 2 photographs.

TRINIDAD

*"Preliminary Report on the Cretaceous and Tertiary Larger Foraminifera of Trinidad British West Indies," by Thomas Wayland Vaughan and W. Storrs Cole. *Geol. Soc. America Spec. Paper 30* (New York, February 25, 1941). 137 pp., 46 pls., 2 figs.

WASHINGTON

*"Course of Columbia River in Southern Central Washington," by Charles R. Warren. *Amer. Jour. Sci.*, Vol. 239, No. 3 (New Haven, Connecticut, March, 1941), pp. 209–32; 2 figs., 1 pl.

WYOMING

*"Critical Structural Features of the Bighorn Mountains, Wyoming," by Max Demorest. *Bull. Geol. Soc. America*, Vol. 52, No. 2 (New York, February 1, 1941), pp. 161–76; 4 pls., 3 figs.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 15, No. 2 (March, 1941).

"New and Little Known Carboniferous Conodont Genera," by E. B. Branson and M. G. Mehl.

"Revision of the Pennsylvanian Conodonts," by Samuel Ellison.

"*Textularia* from the Texas Tertiary," by Flavy E. Davis.

"New Middle Eocene Foraminifera from Southern Alabama and Mississippi," by J. B. Garrett.

"A New Graptolite Horizon in Wisconsin," by Charles E. Decker and E. A. Frederickson, Jr.

"Correlation of Cambro-Ordovician Trilobites from Oklahoma," by E. A. Frederickson, Jr.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 4 (APRIL, 1941), PP. 772-777

THE ASSOCIATION ROUND TABLE

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The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 25, NO. 4 (APRIL, 1941), PP. 778-779

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

JAMES O. LEWIS, lately of Dunn and Lewis, announces the opening of a consulting office at 1912 Commerce Building, Houston, Texas.

DONALD T. GIBSON, of Lubbock, Texas, is in the geological office of the Stanolind Oil and Gas Company at Tyler, Texas.

VAN D. ROBINSON, of the Atlantic Refining Company, has succeeded S. C. GIESEY as secretary-treasurer of the Shreveport Geological Society, Shreveport, Louisiana, following Giesey's resignation from the Stanolind Oil and Gas Company to accept a position with the Union Oil Company at Midland, Texas.

PAUL WEAVER, of the Gulf Oil Corporation, Houston, Texas, gave a paper on "The Salt of the Jurassic of South Arkansas and Its Relation to the Salt Domes of Louisiana, Mississippi, and Texas," before the South Louisiana Geological Society at Lake Charles, Louisiana, March 4.

A. R. DENISON, chief geologist of the Amerada Petroleum Corporation, presented a paper, "The History, Geology, and Geography of the Bermuda Islands," before the Shawnee Geological Society at the monthly meeting on February 27, at Shawnee, Oklahoma.

ARNOLD S. BUNTE, recently in consulting practice at Tulsa, Oklahoma, has joined the Vickers Petroleum Company at Wichita, Kansas.

ARTHUR L. BOWSHER, of the University of Tulsa, presented a paper, "The Mississippian Formations of the Sacramento Mountains, New Mexico," before the Tulsa Geological Society, at Kendall Hall, University of Tulsa, March 17.

W. A. WALDSCHMIDT, of the Colorado School of Mines at Golden, Colorado, addressed the Rocky Mountain Association of Petroleum Geologists at Denver, March 17, on "Cementing Materials in Sandstones and Their Probable Influence on Oil Accumulation."

HUGO R. KAMB, of the Arkansas Fuel Oil Company, talked on "The Olla Field, La Salle Parish, Louisiana," before the Shreveport Geological Society, March 20.

C. V. MILLIKAN, chief petroleum engineer for the Amerada Petroleum Corporation, Tulsa, Oklahoma, gave a series of lectures on "Reservoir Conditions in Oil Fields," at A. & M. College of Texas, April 16, 17, and 18.

S. F. SHAW, consulting engineer of San Antonio, talked before the Fort Worth Geological Society, March 10, on "Factors That Influence the Choice of Gas Lift for Producing Oil."

CARL A. MOORE, of the Standard Oil Company of New Jersey, recently spoke before the geology seminar at Rutgers University on "Some Aspects of Petroleum Geology."

At the regular meeting of the Appalachian Geological Society at Charleston, West Virginia, February 17, ROBERT S. HYDE talked on "Recent Salt Sand Drilling in Harper District, Roane County, West Virginia," and JAMES W. CUMMINS talked on "Depositional Character of the Clinton Sandstone."

SOLON SHEDD, curator of the Branner Geological Library at Stanford University since 1926, died at the age of 80, on March 4. He retired from active service last June. He was widely known for his "Bibliography of California Geology." He was formerly professor of geology at the Washington State College at Pullman, Washington, and for a number of years was State geologist of Washington.

STANLEY W. WILCOX, of the Seismograph Service Corporation, has been transferred from Jackson, Mississippi, to Wichita, Kansas, where he has opened a district office for the region northward to Canada.

LYNN D. ERVIN is on leave of absence from the Stanolind Oil and Gas Company. His address is Company H, Marine Corps Schools, Marine Barracks, Quantico, Virginia. His home address is Route 2, Box 70, Glenwood Springs, Colorado.

RUDOLF MARTIN, of the Shell Oil Corporation, has moved from Wichita, Kansas, to the Caribbean Petroleum Company, Maracaibo, Venezuela.

TRACY GILLETTE, recently at Rochester, New York, may be addressed at the Illinois State Geological Survey Division, Urbana, Illinois.

The Venezuelan Government has granted the Medalla de Honor de Instrucción Pública to L. KEHRER, of the Shell Oil Company of Ecuador, Quito, Ecuador, and to H. D. HEDBERG, of the Mene Grande Oil Company, Barcelona, Venezuela. This medal, the highest scholastic honor to be had in Venezuela, has been presented to these two geologists for their notable contributions to the geology of Venezuela presented in the First and Second Venezuelan Geological Congress and published in the *Boletin de Geologia y Mineria*. The decree appears in the *Official Gazette* of March 10, 1941. The medals were granted at the special request made by the Servicio Técnico de Minería y Geología of the Ministerio de Fomento at the Second Venezuelan Geological Congress in San Cristobal in 1938.

MRS. KATHLEEN PFANNKUCHE, formerly of The Pure Oil Company laboratory at Fort Worth, Texas, addressed the Pacific Section of the Society of Economic Paleontologists and Mineralogists, March 7, at the Clark Hotel in Los Angeles, California. Her topic was "Problems in Cretaceous Correlation of the Gulf Coast." There was a good attendance, and a great deal of interest was shown in the Midway and Navarro, in their relationship to the Danian and the question of the top of the Cretaceous, and in attempting correlations between the Gulf Coast and California.

HORACE DAVIS THOMAS, associate professor of geology at the University of Wyoming, Laramie, has been appointed State geologist.

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FIELD TRIP

WEST TEXAS GEOLOGICAL SOCIETY SPRING FIELD TRIP, MAY 10–11

The West Texas Geological Society will hold its annual Spring Field Trip from Fort Worth to Midland on May 10–11. The leaders of the trip will be M. G. Cheney, V. C. Perini, Morgan E. Roberts, and Gayle Scott. The route will roughly follow Highway 80 from Fort Worth to Midland. Fort Worth headquarters will be at the Blackstone Hotel. The Fort Worth Geological Society will sponsor a meeting in Fort Worth, Friday night, May 9. The following papers will be presented.

Karl Mygdal, "The Search for Oil in the Fort Worth Basin."

C. W. Tomlinson, "Correlation of the Pennsylvanian Rocks of Oklahoma."

M. G. Cheney, "Main Subdivisions of the Lower Pennsylvanian."

H. H. Bradfield, "Classification of Pennsylvanian of North-Central Texas Based on Fossils and Usage."

The night of May 10 will be spent in Abilene where the Abilene Geological Society has arranged for a dinner at the Wooten Hotel and a meeting. Papers to be presented include the following.

W. Armstrong Price, "Calcareous Deposits of the High Plains."

Ed. W. Owen, "Physiographic Phacts and Phancies."

In addition to the papers at both towns, there will be short prepared discussions on points of controversy on the trip presented at the two meetings.

Committee chairmen are as follows.

General chairman—Ronald K. DeFord.
Road Log—Taylor Cole.
Hotel Arrangements—W. M. Osborn.
Traffic—C. A. McCamy
Registration—Walter G. Moxey.
Publicity—Frank Gardner.

Persons going on the trip are urged to make reservations with W. M. Osborn, Box 707, Midland, Texas, for rooms in Abilene where the hotels are very crowded at the present time.